WALKER - ARTIFICAL COLD - OXFORD, 1796

ON THE

# *PRODUCTION*

OF

# ARTIFICIAL COLD.

Dr Lubbock

From the Author's Brother

AN

# ACCOUNT

OF SOME

*REMARKABLE DISCOVERIES*

IN THE

PRODUCTION OF ARTIFICIAL COLD;

WITH

EXPERIMENTS

ON THE

CONGELATION OF QUICKSILVER

IN

*ENGLAND:*

LIKEWISE,

OBSERVATIONS

ON THE

BEST METHODS OF

PRODUCING ARTIFICIAL COLD;

AND THEIR

APPLICATION TO USEFUL PURPOSES IN HOT CLIMATES.

INTERSPERSED WITH

*Philosophical and Explanatory Notes;*

AND

ILLUSTRATED WITH A PLATE,

REPRESENTING THE DIFFERENT KINDS OF APPARATUS WHICH ARE APPLICABLE TO THE VARIOUS PURPOSES REQUIRED.

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*BY RICHARD WALKER.*

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TO

# Sir JOSEPH BANKS, Bart.

*PRESIDENT OF THE ROYAL SOCIETY.*

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Sir,

YOUR own exertions towards the advancement of knowledge, the encouragement you have conſtantly given to the efforts of others, with the elevated ſituation you ſo juſtly fill in the circle of ſcience, naturally prompt the candidate for philoſophic fame to look up to you as his patron.

The greater part of the following pages, as you will perceive, has already appeared before the public, through the moſt reſpectable channel.

These conſiderations, Sir, with the flattering manner in which you were pleaſed to receive the firſt paper, which contained, as I

may

may ſay, the embryo of the ſucceeding ones, induce me to hope this little production may not prove unworthy of your protection.

I have the honour to be,

With the utmoſt reſpect,

SIR,

Your moſt obedient humble ſervant,

R. WALKER.

OXFORD,
September 10, 1796,

# PREFACE.

THE Experiments, *On the Production of Artificial Cold without the Use of Ice*, which form the principal subject of the following papers, having acquired some degree of celebrity in the philosophical world, and likewise grown to some degree of respectability with regard to bulk, several gentlemen have suggested to me the propriety of giving an account of them together, alledging as a reason, that many may wish to purchase these at a small expence, who do not possess, or may not have an opportunity of seeing, the Philosophical Transactions.

I have therefore resolved, as the subject is now, with respect to myself, brought to a conclusion, so far to comply with the opinion

 of

of my friends, as my neceſſary avocations will permit: upon this conſideration, I have thought proper to publiſh the papers as they were read before the Royal Society, and afterwards honoured with a place in the Philoſophical Tranſactions. By adopting this plan, the inconvenience of repetition will unavoidably in a few inſtances occur; but this I preſume, the reader, who is fond of tracing the progreſſive ſteps of ſcience, will readily forgive.

It will doubtleſs be remarked, that this ſubject has been very ſlow in its progreſs under my hands; the principal reaſons for which are, the very ſmall portion of time I have to ſpare out of my buſineſs, and the rare and diſtant opportunities which preſented to me for making ſome of the experiments, particularly thoſe which required a great degree of natural cold; and, moreover, it happened on account of other circumſtances, that of thoſe opportunities which did offer I could catch but few, and theſe chiefly at the moſt unſeaſonable times, being frequently by candle-light, in the ſharpeſt weather of the moſt ſevere winters.

It

It may be neceſſary to obſerve, that whilſt I claim for myſelf an excluſive right to the merit of theſe diſcoveries, if any belong to them, juſtice requires me to declare, that the inaccuracies in ſtyle and language, whatever they be, attach to no one elſe: but theſe, I truſt, will be overlooked, if the experiments be found intereſting, and the relation of them faithful and intelligible.

In the Introduction will be found, I believe, an impartial, though conciſe account, of the ſtate of this ſubject at the *commencement* of theſe experiments; which, with the various notes and obſervations interſperſed in the courſe of this little work, will, I conceive, form a tolerably perfect compendium of this curious branch of experimental philoſophy, and at the ſame time enable the reader to judge of the progreſs I have made in it.

# INTRODUCTION.

THERE are three different methods of producing Artificial Cold, viz. Firſt, by the expanſion or rarefaction of the air; ſecondly, by evaporation with different fluids; and, thirdly, by mixtures, which produce that effect, in conſequence of the ſolution which takes place from the chemical action on each other, of the ſubſtances mixed.

The firſt of theſe, producing effects the leaſt powerful, is ſeldom uſed with that intention; but, as there are ſome curious inſtances in this way, I ſhall mention a few of the moſt ſtriking of them: thus it is found, that a few degrees of cold are produced, by the expanſion of the air in the receiver of an air-pump, when a part of it is haſtily pumped out; and likewiſe by diſcharging the air of an air-gun*, upon the bulb of a thermometer.

But

* Dr. DARWIN's Experiments.—Phil. Tranſ. 1788.

But the moſt remarkable inſtance of this kind, viz. of cold produced by the ſudden rarefaction of the air, is exhibited by the fountain of Hiero, at the Chemnicenſian mines in Hungary. In this machine the air in a large veſſel is compreſſed by a column of water 260 feet high, a ſtop-cock is then opened, and as the air iſſues out with great vehemence, and thus becomes immediately greatly expanded, ſo much cold is produced, that the moiſture from this ſtream of air is precipitated in the form of ſnow, and ice is formed, adhering to the noſle of the cock.

This remarkable circumſtance is deſcribed at large, with a plate of the machine, in Phil. Tranſ. vol. 52.

With reſpect to the ſecond method, that is, by the evaporation of fluids, I ſhall mention thoſe three which are moſt commonly uſed for this purpoſe, viz. vitriolic æther, rectified ſpirit of wine, and water; the former of theſe being the lighteſt and moſt evaporable liquor known, it conſequently produces much greater cold in this way than any other, and is therefore generally uſed for this purpoſe.

This, applied in the common way, that is, by wetting the bulb of a thermometer with it, and blowing on the bulb to haſten the evaporation, produces

produces about thirty degrees of cold; rectified ſpirit of wine, thus treated, about twelve; and water about five, degrees of cold.

Evaporation, though not the moſt powerful in its effects this way, is that which is moſt generally known, and in which we are more immediately intereſted, it being the common proceſs of nature for producing cold, and of which our feelings occaſionally give us ſufficient evidence,* one inſtance of which being remarkable, I ſhall, though it be rather foreign to the ſubject of *artificial* cold, mention here.

The following experiment ſhews the power of the living body for reſiſting heat, when immerſed in a fluid conſiderably *above* its own temperature, particularly in air, that being a bad conductor of heat.

Dr. FORDYCE, Dr. BLAGDEN, and others, went into a room in which the air was ſurpriſingly hot: Dr. BLAGDEN *concluded* theſe experiments,† by going into air heated to 260°, and ſtayed eight or nine minutes; eggs and beef ſteaks being

* Evaporation keeps the body cool in extreme heat:—heat produces perſpiration; and perſpiration, by evaporating, produces cold.

† Phil. Tranſ. 1775, ſee page 485.—See likewiſe, in the ſame volume, more "experiments in an heated room," by Dr. DOBSON.

being placed on a tin * in the ſame place, the firſt were ſoon baked hard, and the latter were perfectly dreſſed in thirteen minutes :—a dog was kept in the air at 220°, for half an hour, without being injured, only panting much, and diſcharging a good deal of ſaliva. In theſe experiments it was found, that the heat of the body was raiſed but little above its natural temperature; but the pulſe ſhewed that the circulation was much accelerated.

But it muſt not be inferred hence, that the natural temperature of the human body is preſerved, when immerſed in a medium much warmer than itſelf, (as in the above experiment, in heated air), ſolely by the cold produced by evaporation, ſince experiments have proved that the living body has a power of *abſorbing* heat, by a change of capacity in the fluids, as well as of *generating* heat.†

The third method, viz. by mixture, being chiefly the ſubject of the following pages, I ſhall refer to thoſe, only ſimply ſtating the extent of our knowledge in this way, at the commencement of the following experiments. This was comprehended in knowing, that there were three

ſalts

* A metal is a much better *conductor* of heat than air; whence the tin communicates its heat much quicker, to the ſubſtance in contact with it, than the air alone.

† CRAWFORD on Animal Heat, p. 386.

ſalts which have the property of producing cold by ſolution in water, viz. ſal ammoniac, which produces about 26 degrees of cold, nitre about 17, and common ſalt only 2 degrees.*

We ſhall indeed find in different authors various mixtures for producing artificial cold; but as none of them exceed in this property, the power of ſal ammoniac alone, when diſſolved in water, they are ſcarcely worth noticing; however, as there is one to which a more wonderful power is aſcribed than the reſt, I ſhall mention it.

This is an experiment of M. HOMBERG,† and conſiſts in pouring a pint and a half of diſtilled vinegar upon two pounds of a powder, compoſed of equal parts of ſal ammoniac and corroſive ſublimate, ſhaking them well together.

It is ſaid that "this compoſition will be ſo very cold, that a man can hardly hold the veſſel in his hands in ſummer; and it chanced, as Monſieur

* "When FAHRENHEIT's thermometer ſtood at 68 degrees, both in the open air, and in the water which was uſed for the experiments, I ſaturated equal portions of water with ſal ammoniac, with ſaltpetre, and with ſea ſalt. The ſal ammoniac made the thermometer ſink from 68 to 42 degrees; hence 26 degrees of cold were produced: the nitre produced 17 degrees, and the ſea ſalt produced only 2 degrees."

WATSON's Eſſays, vol. iii. p. 136.

† Phil. Tranſ. abridged, by MOTTE, vol. ii. p. 7.

Monſieur HOMBERG was making this mixture," before the Society, " that the ſubject froze."

Having met with the above account a ſhort time after I had ſucceeded in producing ice by a ſolution of ſalts in water, during the hotteſt weather of ſummer, I was induced to give this a trial, and therefore immediately (June 30, 1786), prepared a mixture of this kind, in a ſmaller quantity, but found it produced only 32 degrees of cold, which is not more than I have been able to produce, as will be afterwards ſeen, by diſſolving ſal ammoniac *alone* in water.

There is likewiſe a method of BOERHAAVE's,* for making ice, which conſiſts in making ſeveral ſeparate mixtures of ſal ammoniac and water previouſly, and then adding theſe mixtures together: this I likewiſe tried, but, as I expected, found no increaſe of cold thereby. We ſhall now and then meet with an obſervation, that ice was ſometimes produced by frigorific mixtures; but that has been found to happen only when the coldneſs of the air was favourable to it, as in ſpring or autumn.

Mr. BOYLE, who made a great many experiments, and has written a great deal on the production

* Chamb. Cyclop. Article " Freezing mixture."

duction of artificial cold, was, I believe, the firſt perſon who obſerved that ſal ammoniac produces cold by ſolution in water: in his works will be found an account of various experiments made with the uſe of this ſalt, particularly one, entitled "*A new frigorific experiment, ſhewing how a conſiderable degree of cold may be ſuddenly produced without the help of ſnow, ice, hail, wind, or nitre, and that at any time of the year.*" BOYLE's Works, vol. iii. page 144.

This new frigorific experiment conſiſted in diſſolving ſal ammoniac in water, which, Mr. BOYLE obſerves, exceeds very much in this way the power of any other mixture for producing artificial cold then known, making a compariſon of its effects, principally with nitre, which was already known to produce a conſiderable effect this way. Mr. B. obſerves, that in the ſpring and autumn, that is, when the weather was cool, the cold produced by the ſal ammoniac has been ſometimes ſufficient to freeze water; he likewiſe propoſes its uſe for cooling liquors, regretting it was ſuch an expenſive article; but at the ſame time informing his readers, that this circumſtance might in ſome meaſure be obviated, by recovering the ſalt for uſe again by evaporation.

Monſieur

Monſieur GEOFFROY, in his obſervations "on cold diſſolutions and fermentations,"* obſerves, that ſal ammoniac cools the water wherein it is diſſolved more than any other ſalt; that ſometimes, when the temperature was ſufficiently cold, ice has been produced by this mixture; he likewiſe added half an ounce of ſal ammoniac to three ounces of ſpirit of vitriol, which made a violent fermentation, and produced conſiderable cold. He mentions likewiſe various other mixtures of ſalts with water, and ſalts with acids, which he tried; but none whoſe effects are at all equal to the two experiments abovementioned.

It ſeems that a ſubſtitute for ice for the purpoſe of cooling wine and other liquors, in warm countries or ſeaſons, has at different times employed the minds of experimentaliſts in this way, even from BOYLE to the preſent; one inſtance of which is the Abbe NOLLET,† who inſtructed us ſo early as in the year 1756, after mentioning other methods leſs effective, how to cool liquors, particularly wine, by the artificial means of diſſolving chemical ſalts in water. The proceſs he directs is, to cool the pan and the materials previouſly in a well; the temperature of which is

* Phil. Tranſ. abridged by MOTTE, vol. ii. p. 4.

† Hiſt. of the Royal Academy of Sciences at Paris, for the year 1756.

is much colder in hot weather than the air above; then mix the ſalt, either ſal ammoniac or ſalt petre, (preferring the former becauſe it is known to produce moſt cold,) with the water, and immerſe the bottle containing the wine to be cooled, in the mixture thus prepared; he likewiſe adds, to obviate the objection that may be made to the expence of it, that the ſalt may be recovered by evaporation.

I ſhall now conclude this account of the various attempts of different perſons for producing artificial cold without the uſe of ice, with the propoſal of Dr. WATSON for freezing water in ſummer, mentioned in the third volume of his Chemical Eſſays, at page 139; preſuming that if any chemical mixture had been diſcovered which could produce this effect, we ſhould have found it there.

"The poſſibility of freezing water in the middle of ſummer, is rightly enough inferred from this experiment. In a tub, ſuppoſe of three feet in diameter, place a bucket, a little taller than the tub, of one foot in diameter; in the bucket hang a Florence flaſk, or a flat lavender-water bottle, ſo that the mouth of the bottle may be above the rim of the bucket: fill theſe veſſels with water heated, ſuppoſe to 70 degrees: ſaturate the water in the tub with ſal ammoniac, then will the 70 degrees of heat be reduced

reduced to 44; the water loſing, during the ſolution of the ſalt, 26 degrees. The water in the bucket being ſurrounded with this cold fluid will itſelf be cooled; ſuppoſe it to be cooled only to 50 degrees, then, by ſaturating it with ſal ammoniac, it will loſe 26 degrees more of its heat, and be cooled to 24 degrees. The water in the bottle being immerſed in a fluid, heated only to 24 degrees, will ſoon be cooled below the freezing point or 32 degrees, and conſequently will concrete into ice."

This, though an ingenious propoſal, is an experiment, which I ſhould think ſcarcely any perſon, conſidering the dearneſs of ſal ammoniac, ever put *literally* to the teſt:—I have added ſal ammoniac, in fine powder, at the temperature of 70, to water at 50, which produced a cold of 29 only, (the water at 50, being lowered in temperature, by the ſal ammoniac at 70, only *twenty-one* degrees). In this mixture a phial, containing ſome water, was immerſed, but the water was not frozen,* although it was certainly cooled below 32. †

The

* In the courſe of my experiments, I have ſucceeded in freezing water, by immerſing a ſmall phial, containing the water, in a half-pint tumbler, containing a ſolution of ſal ammoniac in water; but, I found it neceſſary, for that purpoſe, that the ſalt, as well as the water, ſhould be at the temperature of 50, previous to their being mixed.

† See the note ‡, at page 25.

The method of producing artificial cold, *with* the uſe of ice, being generally known, it is ſcarcely neceſſary to ſay any thing about it; but, as it will be found that I have occaſionally uſed mixtures of this kind *alone*, and at other times in *conjunction* with my other chemical mixtures, I ſhall juſt remark here, that ice, it has been long known, when mixed with different ſalts, produces cold; particularly with common ſalt, which is the mixture in common uſe for freezing; and likewiſe that ice, in the form of *ſnow*, diſſolved in different liquors, produces cold, particularly in ſpirit of nitre, ſpirit of ſea ſalt, and ſpirit of vitriol.*

There is an old aſſertion, relating to the ſubject of cold, which is, that if water, in a thin veſſel, be immerſed in another veſſel of ſnow, or pounded ice, and the whole placed over a fire, that the water will be frozen; that water, ſubjected thus to the cold of ſnow or ice, a few degrees *below* the point at which water freezes, may acquire the ſame temperature with the ſnow or ice, before this has acquired heat from the fire, and thus be frozen, is certain; but it is abſurd to

* At the temperature of 32°, ſnow, mixed with ſpirit of nitre, produces about 59 degrees of cold; with ſpirit of ſea ſalt, about 53°, and with *undiluted* ſpirit of vitriol, about 35°. See the laſt paragraphs of pages 36 and 71.

to attribute this effect to the diffolution of the ice by heat. I fhould not have thought it worth while to have noticed fo trifling a circumftance, had I not known it to be an opinion commonly received, and as being a *fact* which a perfon fome time fince *unfuccefsfully* undertook to convince me of.

As the principal phenomena in the following papers are illuftrative of the theory of latent heat, as developed by its author, Dr. BLACK, and improved by Dr. CRAWFORD, Dr. IRVINE, and others, and likewife admit of an eafy and fatisfactory explanation thereby, it may not be amifs juft to mention fome of the leading features of this theory, or thofe which immediately apply to this fubject, cold being confidered as merely the diminution of heat.

There are two opinions concerning heat, one of which is, that heat confifts in motion; the other, that it is matter.

I fhall adopt the latter opinion here, thinking it moft confonant with the mode obferved, of explaining the following facts; and becaufe I believe it is now the opinion moft generally received.

Heat

Heat * is a fluid which ſurrounds and pervades all bodies, therefore all *inanimate* bodies naturally acquire and retain the ſame temperature, or ſenſible degree of heat, with that of the medium which ſurrounds them, unleſs this equilibrium be prevented or diſturbed by natural cauſes.

The natural cauſes which may ariſe, ſo as to alter this equilibrium, are ſeveral; but that with which we are at preſent concerned ariſes from the *alteration in the form* of bodies only: thus it is found, that vapour, in being condenſed to a liquid, becomes ſenſibly hotter than before, and that a liquid, in being condenſed to a ſolid, likewiſe becomes hotter; and inverſely, that a ſolid, in changing to a liquid, becomes colder; which is likewiſe the caſe, when a liquid changes to the ſtate of vapour.

Hence it is inferred, that the vaporous ſtate of a body contains more *abſolute* heat than the liquid, and the liquid more *abſolute* heat than the ſolid; but that a portion of this *abſolute* heat, in each inſtance, is fixed or combined with, and makes a part of the ſubſtance, (ſomewhat in the ſame manner that fixed air is condenſed,

* I have uſed the word *heat* here, in compliance with cuſtom; for *fire*, ſtrictly ſpeaking, is the matter, and heat only its diſtinguiſhing property.

in its combination with water), and therefore, whilft in this fixed, combined, ftate, lofes the property of *fenfible* heat, and is therefore called *latent* heat.

Thefe two different ftates of a body, for containing heat, are called their *capacities for heat.*

Thus it is faid, that vapour has a greater capacity for heat than the liquid, and the liquid than the folid form.

This being premifed, the whole of the phenomena of heat and cold, even from the greateft degree of cold known to the higheft ftate of combuftion, become eafily explicable; but it will be fufficient here to fhew how the *lower degrees* of it only are produced.

Therefore, recollecting that folids, in becoming liquid, abforb heat, or become colder, it may be obferved, that when ice, or chemical falts, are diffolved in mineral acids, the capacity of the ice, or falt, for containing heat, is *increafed*, in changing to a liquid ftate; hence a portion of its *fenfible* heat is abforbed, and rendered *latent*, as it is called, whence the temperature of the mixture (the *abfolute* quantity of heat remaining the fame) becomes colder.

The fame circumftance happens, by the diffolution* of falts in water; and likewife, when ice

* It is to be obferved, that fince the change of capacity for heat, in thefe mixtures, is produced by the *diffolution* of the

ice and ſalt are mixed, *both* then becoming liquid; whence, in this caſe, there is an abſorption of heat from *each*.

Likewiſe, when liquids, as ether, rectified ſpirit of wine, or water, evaporate, or expand into vapour, their *capacity for heat* becomes very much *increaſed*, whence a portion of abſolute heat is abſorbed, and the temperature, in conſequence, becomes much colder.

By the expanſion or rarefaction of the air, it is evident that the *capacity for heat* muſt be increaſed, ſince the air then occupies a much larger ſpace than before, whence the quantity of heat it contained being widely diffuſed, the temperature or ſenſible heat muſt conſequently be *diminiſhed*. This accounts for the cold produced in the receiver of an air-pump, when the air is haſtily exhauſted—in diſcharging the air gun—

the ſubſtances mixed, that cold is generated only *during the ſolution* of the ice, ſalts, &c. in the different liquids; and that, unleſs a liquefaction take place, of courſe no cold can be produced. Thus it is found, that ice and ſalt remain a ſolid maſs, if mixed together at a low temperature, viz. at —6°; and thus it is with the other materials, at different temperatures, viz. in mixtures of ice with different acids, very low; (ſee the note at page 72); and probably, with the chemical ſalts and mineral acids, lower ſtill; whence it may hereafter be found, that theſe latter will generate further cold, at a temperature where *ice* and mineral acids ceaſe to produce it.

gun—and likewiſe in the machine, at the Chemnicenſian mines in Hungary, before mentioned; it is neceſſary to add, that when air is much cooled, it depoſits the water, which it before retained, by the ſuperior degree of heat; theſe circumſtances, taken together, account for the whole of this extraordinary phenomenon.

From the inſtances of HEAT, produced by the *condenſation* of liquids into ſolids, in conſequence of the capacity for heat being *diminiſhed*, I ſhall mention thoſe two which relate directly to this ſubject. Thus, if GLAUBER's ſalt be melted over the fire, and ſuffered to cool again in the air, with a thermometer immerſed in it, it will be found, that at the inſtant the ſalt begins to cryſtallize, the thermometer will ſuddenly riſe ſeveral degrees: ſecondly, water, as will be ſeen hereafter, uſually requires to be cooled a few degrees below 32°, its freezing point, before it freezes, and will, if artfully managed bear to be cooled to 21°, or lower, in an open veſſel; but the inſtant it begins to freeze, its temperature always becomes 32°. This circumſtance depends on the quantity of *latent* heat which naturally belongs to water, as a liquid, and which, on its freezing, is let looſe, and becomes *ſenſible* heat. From the ſame cauſe likewiſe, viz. the conſtant evolution of heat during the freezing proceſs, the ſame tempera-

ture

ture is preferved until the whole of the water is frozen;* but the ice will *afterwards* acquire, in more or lefs time, as well as all other bodies, the temperature, whatever it be, of the air, or other medium which furrounds it.

The heat which is produced by the *condenfation* of vapour into a liquid, by which the capacity for heat is *diminifhed*, is familiarly and pleafantly exemplified by the genial warmth that ufually accompanies the fall of rain, in cold feafons.

An example, from the *condenfation* of air, may be taken from the charging an air-gun, by which,

* Moft bodies, in becoming folid, contract in bulk, and become heavier; but water expands in freezing; therefore ice, as is well known, is fpecifically lighter than water. This circumftance feems to be beft accounted for, by attributing it to the particular arrangement the particles of water take, in cryftallizing, as well as moft, or perhaps all bodies in becoming folid, particularly falts, each of which unite at different angles: thus the particles of ice are faid conftantly to join at an angle of 60 degrees, which muft neceffarily increafe its bulk; it is obferved likewife, that ice once formed, expands afterwards ftill more in proportion as it is fubjected to greater cold: thus I have noticed that ice, which has been formed by cold, juft fufficient to freeze it, is flightly convex at top, but, when frozen by extreme cold, is raifed into a perfect cone.

Dr. Blagden has noticed a remarkable circumftance refpecting the cooling of water, which is, that the expanfion commences *before* the water begins freezing, viz. at the temperature of 40°. Phil. Tranf. 1788, p. 311.

The fpecific gravity of water, is to ice, as 8 to 7; therefore water expands in bulk one-eighth, by freezing.

which, the air being ſuddenly compreſſed into leſs compaſs, *its capacity for heat* is conſequently diminiſhed,—whence an increaſe of temperature.* From

* Mr. De Luc, Mr. Lavoisier, and ſome other philoſophers, are of opinion, that the changes of heat and cold, which are known to take place when the *forms* of bodies undergo the changes above-mentioned, depend not upon a change of capacity, but upon chemical *combination* and *decompoſition.*

Thus, by theſe gentlemen, heat is ſuppoſed to be chemically combined with the ſubſtance to which it unites, (as an acid is to an alkali), when it is abſorbed and rendered *latent*, as in the proceſſes of melting, ſolution of ice or ſalts in liquids, and thawing; and that, when the liquids return again to a ſolid form, by cryſtallization, freezing, &c. the heat is again extricated by *decompoſition.*

But the opinion of Dr. Crawford ſeems to be, that the union between the matter of heat, and other ſubſtances, is not by chemical *combination*, but according to that particular ſpecies of union only, by which fixed air and water unite, or perhaps which takes place, by the ſolution of a ſalt in water.

Admitting the laſt opinion to be moſt probable, a happy explanation of it, I conceive, may be given by analogy thus:—Water, it is well known, is in a quantity more or leſs, according to denſity, heat, and other circumſtances, held in ſolution by air. The water thus diſſolved, (not merely ſuſpended, as in miſts), may be ſaid to be *latent*, the air, though replete with water, being tranſparent, and apparently dry; but the ſame air, under different circumſtances of denſity, heat, &c., gives out or depoſits the water again.

Many familiar inſtances will occur to the reader, which might be adduced in proof of this; but I ſhall mention only the following:—" If a large globular glaſs veſſel, with a narrow neck," a Florence flaſk, for inſtance, " be cloſely corked up,

From the consideration of the different quantities of *absolute* heat, of the same body, in the two states of solidity and fluidity, is deduced a method of finding the whole quantity of *absolute* heat which any body contains; and consequently the point of total privation of heat in all bodies. The mean of the calculations already made for this purpose fixes this point at 1428° below 0, of FAHRENHEIT; at which temperature, according to this hypothesis, all bodies would be, if the above calculation be accurate, absolutely cold. †

I refer those, who may wish to be further informed on the curious subject of *latent heat*, to Dr. CRAWFORD's excellent book on Animal Heat, NICHOLSON's Chem. Dict. or his Introduction to Nat. Philos. vol. ii.

It

up, in a clear hot day, the water contained in the apparently dry air will be precipitated, and form a dew in the inside of the vessel, whenever the vessel is cooled; and this dew will vanish, being re-dissolved by the air included in the vessel, as soon as the air regains its heat." * Thus we may say, for the sake of analogy, that the capacity of the air, for water, is *diminished* in the first instance, and in the latter *increased*; and here, I suppose, it will be admitted, that no chemical *combination* or *decomposition* has taken place.

* WATSON's Essays, vol. iii. p. 114.

† For an illustration of this curious rule, see note † at page xxvii.

It is to be obſerved, that FAHRENHEIT's thermometer* is meant here, the ſcale of which commences at thirty-two degrees below the point at which water freezes; FAHRENHEIT, probably, at the time he formed his ſcale, ſuppoſing that to be the utmoſt degree of cold which nature had ever

* "The thermometers moſt in uſe at preſent are FAHRENHEIT's, REAUMUR's, and CELSIUS's. In FAHRENHEIT's ſcale the number of degrees between the freezing and boiling water point is 180; the freezing point being at 32°, and the boiling point at 212°, both above 0°, or the part from which the degrees are reckoned both ways. In REAUMUR's ſcale, the number of degrees between theſe two points is 80, and the freezing point is called 0°, from which the degrees are reckoned both ways. In CELSIUS's thermometer, the interval is divided into 100°, and the freezing point is called 0°, as in REAUMUR's. To reduce theſe ſcales to each other, it muſt be obſerved, that one degree of FAHRENHEIT's is equal to $\frac{4}{9}$ of a degree of REAUMUR, and to $\frac{5}{9}$ of a degree of CELSIUS. Therefore, if the number of degrees of FAHRENHEIT, reckoned above or below the freezing point, be multiplied by 4 and divided by 9, the quotient will be the correſponding number on REAUMUR's ſcale. Or if the multiplier 5, and the diviſor 9, be uſed, the quotient will give the degrees of Celſius's ſcale. And, contrariwiſe, if any number of degrees, either of REAUMUR or CELSIUS, be multiplied by 9, and divided by 4 if of REAUMUR, or by 5 if of CELSIUS, the quotient will give the degrees of FAHRENHEIT, reckoned either above or below the freezing point, as the caſe may be."

NICHOLSON's Chem. Dict. vol. ii. p. 935.

ever produced.* But now, much greater degrees of cold being known to exiſt, the degrees, retaining the ſame ſcale, are counted from o downwards, as well as upwards. Therefore, it becomes neceſſary to uſe the two characters, + *plus* and — *minus*; the former, when it precedes the number of degrees, ſignifying *above* o, and the latter, when it occurs, *below* o. But, in order to avoid unneceſſary repetition, the *minus* character only is given in theſe papers; therefore where *no* character is prefixed, it is to be underſtood to mean ſo many degrees *above* o.

The above remarks on the thermometer will doubtleſs be ſuperfluous to many readers; but to others perhaps they may be acceptable.

* The method which FAHRENHEIT took to fix the o, or commencement of his ſcale, I believe, is not perfectly known; it is commonly ſuppoſed to have been adjuſted by a mixture of ice and ſalt, but this will ſink a thermometer ſeveral degrees below o.

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A well-conſtructed thermometer may be conſidered as the only juſt meaſure of heat and cold. This inſtrument is indeed liable to a *very* ſmall error, in conſequence of the bulb being ſomewhat diminiſhed by the preſſure of the air on the outſide, that effect not being counteracted by the reſiſting force of any included air; but this difference, which depends upon the greater or leſs denſity of the atmoſphere, is too minute to require attention, being at moſt not above *one-tenth* of a degree; and even this minute inaccuracy might, if it were required, be corrected, by attending to the height of the barometer at the time of obſervation.

 The

The moſt remarkable points on FAHRENHEIT's thermometer are the following.

At 600° Quickſilver boils.
212° Water boils.
176° Spirits boil.
§114° Greateſt heat of a hot climate in the ſhade.
112° Fever heat.
§108° Heat of a hot bath.
98° Blood heat, *i. e.* the temperature of the human body in health.
§83° Very hot ſultry weather.*
76° Summer heat.
§62° Moderate heat.†
32° Water freezing.
§20° Very ſharp froſt.
§0° Greateſt natural cold in England.‡
—39° Quickſilver freezes.
§—50° Greateſt natural cold hitherto obſerved.||
§—78½° Greateſt artificial cold hitherto produced. ¶

The degrees marked thus §, do not belong to a ſcale of heat; but thinking it might be uſeful, I have ventured to add them here.

* I ſuſpended a thermometer in the open air, expoſed to the ſun during a very hot day in July: at the hotteſt time of the day (about a quarter paſt three) the thermometer was at 102°—a thermometer hanging at the ſame time in the ſhade, where the ſun never ſhines, was at 81°.

† The temperature of the human body in health is 98°: hence we might be led to ſuppoſe, that its heat would be increaſed or diminiſhed, in proportion as the temperature of the air, or other bodies ſurrounding it, are hotter or colder than itſelf; but experience ſhews, that the temperature of the ſurrounding medium, which tends neither to heat nor cool the human body, is much below its own temperature; viz. in this climate 62°. The reaſon why this is ſo much below the natural heat of the human body, is becauſe the living body has a power of generating heat; the *ordinary* exertion of which power, *exactly* counterbalances the difference; whence, in proportion as the air is hotter or colder than 62°, we feel the ſenſation of heat or cold. 55° is temperate heat, on FAHRENHEIT's ſcale.

‡ The thermometer has been once obſerved ſomewhat under this point. See the note at page 41.

|| This was obſerved by Mr. M'NAB in Hudſon's Bay—probably in more northern climates the cold may ſometimes exceed this.

¶ This was effected by Mr. M'NAB at Hudſon's Bay.—See the note † at page 72.

A *ſpirit* thermometer is uſed to indicate any degree of cold exceeding —39°; ſee the laſt paragraph but one of page 51; ſee likewiſe the note at page 73.

Some

Some perſons have propoſed, ſince the diſcovery of the congelation of quickſilver, to fix the zero of FAHRENHEIT's ſcale at the freezing point of quickſilver; this indeed naturally applies to a *mercurial* thermometer; becauſe the power of any liquor for meaſuring heat and cold is limited at its boiling and freezing points. But might it not be more convenient, if an alteration were about to be adopted, to place the cypher at *a hundred degrees* below the point, where it now is? thus, in all probability, the uſe of *negative* degrees, would be no longer neceſſary; and it may be obſerved, that the degrees of cold known, as appears above, approximate ſufficiently near to this point, to authorize ſuch a ſcale; for then, the *laſt point* noticed in this ſcale, would be (inſtead of $-78^\circ\frac{1}{2}$) $21^\circ\frac{1}{2}$; at leaſt this ſcale might ſuffice until the gentlemen who are at preſent engaged in this enquiry, (or ſome other perſon), ſhall have determined *preciſely* the natural zero, that is, the true point of abſolute cold, or total privation of heat. At preſent this matter ſtands thus:—Dr. CRAWFORD's calculation makes it to be at near 1500°,* but Mr. KIRWAN's† *only* at 1268°, below the 0°, or zero, of FAHRENHEIT.

All

* CRAWFORD on Animal Heat, p. 477.

† See Mr. KIRWAN's theorem, for aſcertaining this point.
NICHOLSON's Introd. to Nat. Phil. v. ii. p. 119.

This theorem was, I believe, firſt diſcovered by Dr. IRVINE; and may be briefly exemplified thus:—The whole quantities

All the following experiments, where the object was merely to aſcertain the power of any mixture for producing cold, were made on a very ſmall ſcale, viz. in a ſmall thin wine-glaſs: and thoſe for freezing water, &c. in a tumbler, the liquor to be frozen being contained in a ſmall thin phial; but for this purpoſe, likewiſe, a wine-glaſs will ſuffice, the liquor being then contained in a ſmall thin tube.

The ſame thermometer was uſed in all the experiments, without receiving any injury, though the quickſilver within has been repeatedly frozen.

quantities of heat contained in ice and water, having been found by experiments on their different capacities for heat, to be as 9 to 10; it follows, that when water freezes, it gives out one-tenth of its whole heat; this tenth part is here reckoned to amount to 130°; conſequently its whole heat is ten times 130, or 1300, when its temperature is 32° above FAHRENHEIT'S zero; whence the natural zero is, by this calculation, at — 1268.°

But others make one-tenth of the abſolute heat of water at the temperature of 32°, to be 146° (NICHOLSON'S Chem. Dict. p. 377) which fixes this point, *by the ſame rule*, at — 1428°.

# AN ACCOUNT
## OF SOME
# NEW EXPERIMENTS
## ON THE
# PRODUCTION OF ARTIFICIAL COLD;

In a Letter from THOMAS BEDDOES, M.D.
to Sir JOSEPH BANKS, Bart. P.R.S.

PAPER I.
READ MAY 10, 1787.

DEAR SIR, *Oxford, May 2, 1787.*

MR. WALKER, apothecary to the Radcliffe Infirmary here, has been engaged upwards of a year in a ſeries of experiments on the means of producing Artificial Cold, ſeveral of which ſeem to me to be very remarkable, and ſuch as, conſidering their novelty, and the attention which has lately been paid to this ſubject, I flatter myſelf, will be found to deſerve a place among the Tranſactions of the Society over which you preſide.

Mr. WALKER, in his firſt experiments, found, as BOERHAAVE had done before him, that ſal

 ammoniae,

ammoniac, as well as nitre, well dried in a crucible, and reduced to a fine powder, will produce a greater degree of cold than if they had not received this treatment. But BOERHAAVE, by ſal ammoniac, lowered the temperature of water only by 28°; whereas Mr. WALKER obſerved his thermometer to fall 32°, and when he uſed nitre 19°. It occurred to him, that the combination of theſe ſubſtances would produce a greater effect than either ſeparately; and he found that this was really the caſe. A propoſal for freezing water in ſummer, mentioned by Dr. WATSON (Eſſays, iii, 139.), determined him to attempt the ſame thing in this way: accordingly, April 28, 1786, the thermometer ſtanding at 47°, he made a ſolution of a powder, conſiſting of equal parts of ſal ammoniac and nitre, in a baſon, by means of which he cooled ſome water, contained in a glaſs tumbler, to 22°. To this he added ſome of the ſame powder, and immerſed two very ſmall phials in it; one containing boiled, the other unboiled water; when he ſoon found the water in the phials to be frozen, the unboiled freezing firſt.

Having obſerved that GLAUBER's ſalt,* when it retains its water of cryſtallization, produces cold

* I was diſcouraged from trying this ſalt a conſiderable time in conſequence of having been informed (WATSON's Eſſays, vol.

cold during its ſolution, he thought of adding this to his other powers,* and July 18, 1786, reduced the thermometer 46 degrees. In this experiment the following proportions were uſed: the temperature of the air being 65°, to water four ounces, at 63°, were added (by troy weight,)

| | |
|---|---|
| Of ſal ammoniac eleven drachms, thermometer ſunk to 32°, that is - - - - - - - | 31° |
| Of nitre ten drachms, thermometer ſunk to 24°, that is - - - - - - - - - | 8° |
| Of GLAUBER's ſalt two ounces, thermometer ſunk to 17°, that is - - - - - - | 7° |
| | 46° |

In

vol. iii, p. 136.) that it produced heat; but finding that when *freſh* powdered, it diſſolved in the mouth with a ſenſation of coldneſs, the uſual teſt with me of a ſalt having the quality of producing cold by ſolution in water, it being in fact the ſame thing, I reſolved to try it. I ſuppoſe it had hitherto been tried in an effloreſcent ſtate, for then, when mixed with water, heat *is* produced.

* I was led to expect that the cold might be increaſed by uſing more ſalts than one, from the conſideration that water, already ſaturated with one kind of ſalt, will diſſolve a portion of a ſecond, and after that, a portion of a third, or even more; therefore my next object was to diſcover what ſalts were fitteſt for my purpoſe this way; expecting, as experiment proved, that each might impart a ſhare likewiſe, of its property of producing cold; thus four ſalts, I have found, will produce greater cold than three only; for if the mineral alkali be added after the three which compoſe this frigorific mixture, two or three degrees *more* cold will be produced.

In this way he froze water on a day ſo hot that the thermometer in the ſhade ſtood at 70°. By firſt cooling the ſalts and water in one mixture, and then making another of theſe cooled materials, he ſunk the thermometer 64 degrees.

Auguſt 28. The temperature of the air being 65°, half an ounce of rectified ſpirit of wine was diluted with three ounces and an half of water, and immerſed in the ſame frigorific mixture.* When cooled to 24°, it began to freeze. A quantity of the neutral ſalts, likewiſe cooled in the mixture, was put into the diluted ſpirit, when the thermometer fell to 4°; ſo that the liquor was cooled 69 degrees.

Spirit of nitre, diluted in the manner dedeſcribed by Mr. Cavendish, (Phil. Tranſ. vol. lxxvi, part 1.)† having reduced the thermometer to

* The ſpirit was added to the water, merely to lower the freezing point of the liquor; that I might have an opportunity of trying the effects of the ſalts in liquor at a lower temperature than water alone, I thought, could be cooled to.

† Mr. Cavendish having found that the nitrous acid he uſed, required to be previouſly diluted, in order to bring it to the beſt ſtrength, for producing artificial cold with ſnow: in the paper alluded to (page 143,) he gives directions how this is to be done. The meaning of my note, whence this paragraph

to — 3°, ſal ammoniac was added, upon which it fell to — 15°.

Nitrated volatile alkali,* during its ſolution in water, reduced the thermometer 35 degrees, (from 50° to 15°); but the cold was not increaſed by ſal ammoniac or nitre.

Mr. WALKER's moſt remarkable experiment was made on the 21ſt of March, 1787, when he found that nitrous acid, when poured upon GLAUBER's ſalt,† produced effects nearly the ſame

paragraph was taken, being totally different, I ſhall tranſcribe it here:—"Nov. 13th, 1786, I added pounded ice to nitrous acid at 40°, until the thermometer ſunk to — 3°; and then, by adding ſal ammoniac in powder, the thermometer ſunk to — 15°."

* Having found that ſal ammoniac and nitre produced more cold jointly than ſeparately, I expected that nitrous ammoniac *alone* might exceed them, even when their power was united; this proved to be the caſe; and conſequently common ſal ammoniac, which has hitherto ſtood foremoſt in the power of producing cold by ſolution in water, muſt now give place to nitrous ammoniac, which, as will afterwards be found, exceeds it in this property to a very conſiderable degree.

† This was my firſt attempt, for producing cold, by diſſolving ſalts in an *acid*; and I was not a little pleaſed to find the thermometer ſink by this means, from 50° (the temperature of the air and materials at the time) to 10°: it immediately occurred to me, that the *concentrated* ſtate of an acid, might not

ſame as when it is poured on pounded ice; and that the cold, thus produced, is rendered ſtill more intenſe by the addition of ſal ammoniac in powder.

Mr. Walker, by many trials, diſcovered that the beſt proportion of theſe ingredients is the following:—of concentrated nitrous acid, two parts by weight, of water one part; of this mixture, cooled to the temperature of the atmoſphere, 18 ounces, of Glauber's ſalt a pound and an half (avoirdupois), and of ſal ammoniac twelve ounces. On adding the Glauber's ſalt to the nitrous acid, thus diluted, the thermometer fell from 51° to −1°, or 52 degrees; and, on adding the ſal ammoniac, it fell to −9°, that is, full 60 degrees. Nitrated volatile alkali, employed inſtead of ſal ammoniac, produced a cold rather more intenſe.

By

not be the fitteſt for my purpoſe; I therefore diluted it with water, and found my conjecture verified.

The inſtant I had ſucceeded ſo well, in my experiment with the *nitrous acid* and Glauber's ſalt, the congelation of quickſilver preſented itſelf, as an object within my reach; for I well knew there could be no obſtacle to the ſucceſs of ſuch a ſingular experiment; unleſs I ſhould find the *freezing point* of my frigorific mixture to be (which was very unlikely) at a degree of cold *leſs* than that at which quickſilver freezes.

By means of this mixture, in a very few minutes, in the elaboratory before the claſs, I froze ſome ſpirits above proof, diluted with an equal bulk of water; and another gentleman this day ſunk the thermometer 68 degrees.

On April 20th, 1787, Mr. WALKER effected the congelation of quickſilver by a combination of theſe mixtures, without a particle of ſnow or ice. When he began his experiment, the temperature of the mercury was 45°; ſo that the freezing point of that metal being —39°, there were produced 84 degrees of cold.

This experiment was performed as follows; four pans, of ſizes progreſſively diminiſhing, ſo that one might be placed within the other, were procured.

The largeſt of theſe pans was placed in another veſſel ſtill larger, in which the materials for the ſecond frigorific mixture were thinly ſpread, in order to be cooled; the ſecond pan, containing the liquor, viz. vitriolic acid, properly diluted, was placed in the largeſt pan; the third pan, containing the ſalts for the third mixture, was immerſed in the liquor of the ſecond pan; and the liquor for the third mixture was put into wide-mouthed phials, which were immerſed

immerſed in the ſecond pan likewiſe, and floated round the third pan: the fourth pan, which was the ſmalleſt of all, containing its cooling materials, was placed in the midſt of the ſalts of the third pan.

Of the materials for the mixtures to be made in theſe four pans, the firſt and ſecond conſiſted of diluted vitriolic acid and GLAUBER's ſalt, the third and fourth of diluted nitrous acid, GLAUBER's ſalt and ſal ammoniac, in the proportions aſſigned.

The pans being adjuſted in the manner above deſcribed, the materials of the firſt and largeſt pan were mixed: this mixture reduced the thermometer to 10, and cooled the liquor in the ſecond pan to 20; and the ſalts for the ſecond mixture, which were placed underneath in the large veſſel, nearly as much. The ſecond mixture was then made with the materials thus cooled, and it reduced the thermometer to 3°. The ingredients of the third mixture, by immerſion in this, were cooled to 10°, and when mixed reduced the thermometer to — 15°. The materials for the fourth mixture were cooled by immerſion in this third mixture, to about — 12°. On mixing, they made the mercury in thermometer ſink rapidly, and, as it appeared to Mr.

WALKER,

WALKER, below $-40°$, Its thread ſeemed to be divided below that point; but the froth occaſioned by the ebullition of the materials, prevented his making ſo accurate an obſervation as he could have wiſhed.

The reaſon why this laſt mixture reduced the thermometer more than the third, though both were of the ſame materials, and the laſt at a lower temperature, Mr. WALKER imagines to have been partly becauſe the fourth pan had not another immerſed in it to give it heat, and partly becauſe the materials were reduced to a finer powder.

I ſhould imagine, that mercury reduced to its freezing point, will freeze more quickly than water reduced to its freezing point; becauſe it appears, from experiments on their capacity for heat, that the latter of theſe bodies has ſo much more latent heat in its liquid ſtate; which greater quantity of latent heat muſt, as it becomes ſenſible, more retard the congelation.

I forbear to enumerate many variations of theſe experiments, which Mr. WALKER has among his notes; but there is one mixture, which, though its power is not equal to that which I have laſt deſcribed, may prove very ſerviceable in experi-

ments

ments of this nature, on account of its cheapneſs. It conſiſts of oil of vitriol,* diluted with an equal weight of water: added to GLAUBER's ſalt, it produces about 46 degrees of cold. The addition of ſal ammoniac renders it more intenſe by a few degrees. One remarkable circumſtance occurred to Mr. WALKER, as he was endeavouring to aſcertain the beſt ſtrength of the vitriolic acid: he happened to be trying a mixture of two parts of oil of vitriol and one of water, when he obſerved, that, at the temperature of 35°, the mixture coagulated as if frozen, and the thermometer became ſtationary; but, on adding more GLAUBER's ſalt, it fell again, after ſome little time; but ſo great a cold was not produced † as when this circumſtance did not occur,

* I had no ſooner ſucceeded ſo well with the nitrous acid, than I was led to try the other mineral acids, which are known to produce cold, though in a ſmaller degree, with ſnow; viz. the marine acid, and the vitriolic acid; and, as I expected, found a ſimilar effect in a weaker degree. I was induced to notice particularly the vitriolic acid; thinking from its cheapneſs, and neatneſs, it might hereafter be applied to ſome uſeful purpoſe.

† This is noticed, becauſe it has been found, by experiments for producing cold, by adding ſnow to the mineral acids, that is, the nitrous or vitriolic acid, (the marine acid being ſeldom uſed for this purpoſe), that a greater degree of cold is produced when the ſnow or ice is added to the acid, in a ſtate of *congelation*, than when added to it in a liquid ſtate.

cur, and when the acid was weaker. The ſame appearance of congelation took place with other proportions of acid and water, at other temperatures.

Mineral alkali, when it retained its water of cryſtallization, added to ſome of theſe mixtures, heightened their effects.* But when it had loſt this water, it rather produced heat than cold; and the ſame thing is alſo true of GLAUBER's ſalt. This circumſtance leads us, in ſome meaſure, to the theory of theſe phenomena. Water undoubtedly exiſts in a ſolid ſtate in cryſtals; it muſt therefore, as in other caſes, abſorb a determinate quantity of fire, before it can return to its liquid ſtate. On this depends the difference between GLAUBER's ſalt and foſſil alkali, in their different ſtates of cryſtallization and efflorefcence. The ſame circumſtance too enables us to underſtand the great effect of GLAUBER's ſalt, which, as far as I recollect, has the greateſt quantity of water of cryſtallization.

Thoſe,

* The mineral alkali, by ſolution in water, will produce fifteen degrees of cold; GLAUBER's ſalt only eleven; and if the former ſalt be ſubſtituted for the GLAUBER's ſalt, in the mixture conſiſting of three ſalts before mentioned, the cold produced will be rather greater; but as the difference is not conſiderable, and GLAUBER's ſalt is much cheapeſt, I have commonly uſed it.

Thofe, therefore, who fhall choofe to purfue the path which Mr. WALKER has opened to them, would do well to try combinations of falts, containing much water of cryftallization; but they muft take care, left the effect fhould be diminifhed or deftroyed by the formation of compounds that fix a fmaller quantity of fire. It is however but juftice to Mr. WALKER to obferve, that he has carried his experiments in this way very far, and with great ingenuity.

I have the honour to be, &c.

THOMAS BEDDOES.

EXPERIMENTS

# EXPERIMENTS

ON THE

# PRODUCTION OF ARTIFICIAL COLD;

*BY MR. RICHARD WALKER,*

APOTHECARY TO THE RADCLIFFE INFIRMARY, AT OXFORD:

In a Letter to HENRY CAVENDISH, Efq. F.R.S. and A.S.

PAPER II.

READ JUNE 5, 1788.

SIR,

THE Royal Society having been pleafed to infert, among their Tranfactions for laft year, an account of fome experiments of mine, relating to the production of Artificial Cold, tranfmitted in a Letter from Dr. BEDDOES, I am induced to mention a few I have made fince.

Your zealous attention to this fubject, under whofe aufpices this, as well as other branches of Natural Philofophy, hath received confiderable improvement, will, I hope, apologize for the liberty I have taken in addreffing myfelf to you, efpecially fince any new and ufeful facts I may have afcertained are principally owing to thofe endeavours your excellent papers have excited in me.

My

My moſt powerful frigorific mixture is the following: of ſtrong fuming nitrous acid, diluted with water, (rain or diſtilled water is beſt), in the proportion of two parts of the former to one of the latter, each by weight, well mixed, and cooled to the temperature of the air, three parts; of GLAUBER's ſalt four parts; of nitrous ammoniac three and a half parts, each by weight, reduced ſeparately to fine powder. The GLAUBER's ſalt is to be firſt added to the diluted acid, the mixture well ſtirred, and immediately afterward the powdered nitrous ammoniac, again ſtirring the mixture: to produce the greateſt effect, the ſalts ſhould be procured as dry and tranſparent as poſſible, and uſed freſhly powered. Theſe ſeem to be the beſt proportions, when the temperature of the air and ingredients is 50°; as the temperature at ſetting out is higher or lower than this, the quantity of the diluted acid will evidently require to be proportionably diminiſhed or increaſed. This mixture is but little inferior to one made by diſſolving ſnow in nitrous acid; for it ſunk the thermometer from 32° to —20°; perhaps it may be poſſible to reduce the ſalts to ſo fine a powder as to make it equal. In this laſt experiment the diluted acid was equal in quantity to the GLAUBER's ſalt, being four parts each, the nitrous ammoniac three and an half, as before.

A powder compoſed of ſal ammoniac five parts, nitre four parts, mixed, may be ſubſtituted in the ſtead of nitrous ammoniac, with nearly equal effect, and in the ſame proportion.

Cryſtallized nitrous ammoniac, reduced to very fine powder, ſunk the thermometer, during its ſolution in rain water, 48 degrees from 56°, the temperature of the air and materials to —8°; and when evaporated gently to dryneſs, and finely powered, it ſunk the thermometer 49 degrees to 7°, the temperature of the air and materials being as before at 56°: therefore, in this ſalt, (which produces, as appears above, a much greater cold, during its ſolution in water, than any other hitherto known), the water of cryſtallization is not in the leaſt conducive to that effect.*

I expected, that by diluting the ſtrong nitrous acid to the proper ſtrength with ſnow, inſtead of water, by which its temperature would be much reduced, and then adding the ſalts, a much greater degree of cold might be produced; but,

* The cold produced by the ſolution of the different ſalts in the *mineral acids*, depends principally, perhaps entirely, upon the quantity of water, in a ſolid ſtate, in the ſalts; but not in the cold produced by ſolutions in water. In either inſtance it ſeems, however, that thoſe ſalts which diſſolve quickeſt produce moſt cold.

but, by various diverſified trials, I found but little advantage gained; I ſhall therefore forbear mentioning the particulars. In the courſe of this winter ſome diluted nitrous acid, in a wide mouthed phial, was immerſed in a freezing mixture; when cooled to about —32°, it froze entirely to the conſiſtence of an unguent, when the thermometer ſuddenly roſe to —2°:* on adding ſome ſnow that lay by me, it became again liquid, and the mercury ſunk into the bulb of a thermometer graduated to —76°. I know not its exact ſtrength, but by the effect imagine it might correſpond nearly with that which is capable of the *eaſieſt* point of ſpirituous congelation. †

Cold

* For ſimilar inſtances, in which the nitrous acid bore to be cooled very far below its freezing point, ſee Phil. Tranſ. 1786, page 252.

† The nitrous acid, and vitriolic acid, have each what is called a ſtate of *ſpirituous* congelation, and, likewiſe, of *aqueous* congelation: the former implies, that the frozen acid is in a *concentrated* ſtate, the latter in a diluted ſtate. Much greater cold is produced by adding ſnow to either of theſe acids in a ſtate of *ſpirituous* congelation, than in a fluid ſtate; but little or none, if the acid be in the ſtate of *aqueous* congelation.—Phil. Tranſ. 1786, page 261.

The reaſon why more cold is produced by adding ſnow to an acid in a *frozen* ſtate, than in a fluid ſtate, is, becauſe its capacity for heat is increaſed, in becoming liquid, as well as that of the ſnow; therefore *each*, in that inſtance, abſorbs a portion of ſenſible heat.

Cold, I have found, may be produced by the union of ſuch ſalts as on mixing are decompoſed, and become liquid, or partially ſo. The mineral alkali produces this effect with all the ammoniacal ſalts; but with nitrous ammoniac to a conſiderable degree.

The mineral alkali added in powder to nitrous acid, diluted as above, ſunk the thermometer 22 degrees only, from 53°—(temperature of air and materials) to 31°.

This ſalt contains nearly as much water of cryſtallization as GLAUBER's ſalt, and produces more cold during its ſolution in water than that ſalt.

The reaſon why it produced leſs when added to an *acid* than the neutral ſalt does, is perhaps ſufficiently evident; for I have obſerved the thermometer to be ſtationary, or even to riſe, during the violent effervеſcence produced on mixing thoſe materials, and to ſink as ſoon as that ceaſed.

GLAUBER's ſalt diſſolved indifferently in rectified ſpirit of wine, and produced neither heat nor cold; the diſpoſition to produce cold, during its ſolution, being perhaps exactly counteracted by the tendency which the diſſolved ſalt hath in uniting with the ſpirit to produce heat.

 Epſom

Epſom ſalt,* during ſolution in the diluted nitrous acid, produced nearly as much cold as GLAUBER's ſalt: the ſmall difference there is between them, as to this effect, may be owing to the former containing rather leſs water in its cryſtals.

GLAUBER's ſalt, liquified by heat, was ſet to cool; when its temperature was reduced to 70°, it became ſolid, and the thermometer immediately roſe eighteen degrees, to 88°.

Does not the quantity of ſenſible heat evolved by this ſalt, in becoming ſolid, indicate its great capacity for heat, in returning to a liquid ſtate, and conſequently account in a great meaſure for its producing ſuch intenſe cold during ſolution in the diluted mineral acids?

Two ſalts, alum and Rochelle ſalt, each contain nearly as much water of cryſtallization as GLAUBER's ſalt; but produced neither of them any conſiderable effect during ſolution in the diluted nitrous acid; the latter made the thermometer riſe: neither did their temperatures increaſe, like that ſalt, in changing from a liquid to a ſolid ſtate.

From the obvious application of artificial frigorific mixtures to uſeful purpoſes, in hot climates eſpecially, where the inhabitants ſcarcely know

* EPSOM ſalt *in cryſtals* is meant here; not that which is commonly ſold at the ſhops, under the name of bitter purging ſalt.

know, by the ſenſe of feeling, winter from ſummer,* it may not be amiſs to hint at the eaſieſt and moſt œconomical method of uſing them.

For

* In countries between the Tropics (ſays Dr. MOSELY, in his Treatiſe on tropical diſeaſes, and the climate of the Weſt Indies, page 2, &c.) the heat is nearly uniform, and has ſeldom been known to vary through the year, on any one ſpot, either by day or night, ſixteen degrees; the mean heat on the coaſt and plains not much elevated above the level of the ſea,† is about 80° of FAHRENHEIT. In this climate there is generally not above ſix degrees difference of heat between the coldeſt ſeaſon in winter and the hotteſt ſeaſon in ſummer.—Dr. MOSELY (page 52) obſerves, "The gratefulneſs of cool liquors, in hot climates, is among the firſt ſenſations of luxury. A glaſs of water, or wine, that has been much cooled, produces a very different effect on the ſtomach, as well as on the palate, to what either do in an equal ſtate of heat with the atmoſphere. A late diſcovery for generating ice, from an artificial frigorific compoſition, (alluding to the frigorific mixture of GLAUBER's ſalt and diluted vitriolic acid, deſcribed in the firſt paper), will be of great benefit in tropical countries, as there is no place ſo ſituated, where this compoſition will not afford as much inſtantaneous refrigeration as can be required, either for the purpoſe of medicine, or for the luxury of the table."

† It is well known there are mountains even under the equator, that are conſtantly covered with ice and ſnow.

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At Kingſton, in Jamaica, the heat varies very little; the thermometer ranging from 85° to 90°, during the hotteſt time of the day, at the hotteſt ſeaſon of the year; and, in the cooleſt ſeaſon, at the coldeſt times, juſt before ſun-riſe, it ranges from

 70° to

For moſt intentions, perhaps, the following cheap one may be ſufficient: of ſtrong vitriolic acid, diluted with an equal weight of water, and cooled to the temperature of the air, any quantity; add to this an equal weight of GLAUBER'S ſalt

70° to 77°. Dr. HUNTER, (by whom this account is given), has once ſeen the thermometer ſo low as 69, and twice, as high as 91°. The mean temperature of Kingſton, being nearly level with the ſea, is about 80°, as indicated by the ſprings, which give very nearly the mean temperature ‡ in any climate.—Phil. Tranſ. 1788.

‡ See KIRWAN'S treatiſe on the temperature of different latitudes.

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At Bengal the climate is exceſſively hot, the thermometer being ſeldom under 98°, and often at 104°.—Phil. Tranſ. 1767.

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The difficulty with which the natives of hot countries are perſuaded that water is ever in a ſolid ſtate, I have been repeatedly aſſured of; but I ſhall give the anſwer here, which the King of *Siam* made to the Dutchman, who informed him, that water in his country would ſometimes, in cold weather, be ſo hard, that men walked upon it, and that it would bear an elephant:

"Hitherto I have believed the ſtrange things you have told me, becauſe I look upon you as a ſober man; but now I am ſure you lie."—LOCKE'S Eſſay on the Human Underſtanding, b. iv. c. 15.

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In order to remove any objection that might be ſtarted, againſt the power of my ſtrongeſt frigorific mixture, for freezing water or creams, in the hotteſt climate, at the hotteſt ſeaſon, I purpoſely made an experiment, in which the veſſel, as well as

ſalt in powder: this is the proportion, when the temperature ſet out with is 50°, and will ſink the thermometer to 5°; if higher, the quantity of ſalt muſt be proportionably increaſed.

The

as the materials, were heated to 112°; the materials were then mixed ſuddenly, when the thermometer ſunk to 24°.

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Although ice has never hitherto been ſeen, that I know of, *within* the tropics, it is well known that it is procured by art, very near thoſe latitudes. Thus Sir ROBERT BARKER (Phil. Tranſ. 1775,) deſcribes the proceſs at large, which depends principally upon evaporation; by which ice is made at Allahabad, Mootegil, and Calcutta, in the Eaſt Indies, lying between $25\frac{1}{2}$ and $23\frac{1}{2}$ North lat. where he obſerves enough is made, during the winter months, to ſupply the tables in ſummer. The method is briefly this:—Soft water is firſt boiled, and towards the evening poured into ſhallow porous pans, placed in ſhallow pits, the bottoms of which are ſtrewed with ſugar canes, or the dried ſtems of corn. Early in the morning the ice-makers collect the ice, that has been formed during the night, which is found to vary in quantity, according as the temperature of the air and other circumſtances, depending upon evaporation, are more or leſs favourable for the production of it, and depoſit it in the ice-houſe. Sir ROBERT BARKER adds, that he has frequently regaled with ices when the thermometer ſtood at 112°, in the ſhade. He obſerves, that clear ſerene weather is more favourable than cloudy or windy weather. At the latter place, natural ice, in any of the waters, was never found, that he could hear of; nor has the thermometer been remarked to ſink to 32°; and, at the former, very few only have diſcovered any natural ice, and that but ſeldom.

Sir ROBERT BARKER obſerves (page 203 of the ſame vol.) that the *leaſt* height he has ſeen a thermometer at, at Allahabad,

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The obvious and beſt method of finding the neceſſary quantity of any ſalt to produce the greateſt effect by ſolution in any liquid, at any given temperature, is by adding it gradually until the thermometer ceaſes to ſink, ſtirring the mixture all the while.

If a more intenſe cold be required, double aqua fortis, as it is called, may be uſed; GLAUBER'S ſalt, in powder, added to this, produces very nearly as much cold as when added to the diluted nitrous acid: it requires a rather larger quantity

in the open air, is 42°, at ſeven in the morning, in January; but obſerves, it might probably have been lower during the night. The *greateſt* height, in the ſhade, 114°, in June, at noon.

Dr. BLACK has given a paper, in the ſame volume, on "*The ſuppoſed effect of boiling upon water, in diſpoſing it to freeze more readily, aſcertained by experiments.*" In this paper it appears, that water, which had boiled ſome time, froze more readily than water which had not been boiled; and the Doctor accounts for it, by ſuppoſing, that as water by boiling parts with ſome of its air, that whilſt it is expoſed to a freezing atmoſphere, (for theſe experiments were made in the natural cold), the air, in entering the water again, produces (he thinks) agitation ſufficient, though imperceptible to the eye, to freeze the water, as ſoon as it is cooled to 32°, or a little lower. Hence the utility, he remarks, of boiling the water, before it is ſubjected to the above proceſs, in the Eaſt Indies; otherwiſe, he believes the cold of that climate, even aſſiſted by the power of evaporation, would not be ſufficient to freeze the water.

tity of the ſalt, at the temperature of 50°, about three parts of the ſalt to two parts of the acid: it will ſink the thermometer from that temperature nearly to 0°, and the conſequence of more ſalt being required is, its retaining the cold rather longer.

This mixture has one great recommendation, a ſaving of time and trouble. A little water in a phial, immerſed in a ſmall tea-cup of this mixture, will be ſoon frozen in ſummer; and if the ſalt be added in cryſtals unpounded to double aqua fortis, even at a warm temperature, the cold produced will be ſufficient to freeze water or creams; but if diluted with one fifth its weight of water, and cooled, it is about equal to the diluted nitrous acid above mentioned, and requires the ſame proportion of the ſalt.

A mixture of Glauber's ſalt and diluted nitrous acid ſunk the thermometer from 70° (temperature of air and ingredients) to 10°.

The cold in any of theſe mixtures may be kept up a long time by occaſional additions of the ingredients in the proportions mentioned.

A chemiſt would make the ſame materials ſerve his purpoſe repeatedly.

Equal parts of ſal ammoniac and nitre in powder make a cheap and convenient compoſition

tion* for producing cold by ſolution in water; it will, by the following management, freeze water or creams at midſummer in this climate.

June 12th, 1787, a very hot day, I poured four ounces, wine meaſure, of pump water, at the temperature of 50°,† upon three ounces, averdupois weight, of the above powder, previouſly cooled by immerſing the veſſel containing it in other water at 50°, and after ſtirring the mixture its temperature was 14°; ſome water contained in a ſmall phial, immerſed in this mixture, was conſequently ſoon frozen.

This ſolution was afterwards evaporated to dryneſs, in an earthen veſſel, reduced to powder, and added to the ſame quantity of water, under the ſame circumſtances as before, when it again ſunk the thermometer to 14°.

Since that time, I have repeatedly uſed a compoſition of this kind for the purpoſe of freezing water,

* After I had ſucceeded in freezing water in ſummer by one mixture, my next endeavour was to find the cheapeſt, or which came nearly to the ſame end, a proceſs in which the materials were eaſily and repeatedly recoverable for uſe;—after many unſucceſsful attempts, I found *this* the only one.

† It is well known that water at ſprings retains nearly the ſame temperature winter and ſummer, viz. about 50°, to which temperature the water may be reduced during the warmeſt weather, by pumping off ſome firſt.

water, &c.* without obſerving any diminution in its effect after many evaporations.†

The cold may be œconomically kept up and regulated any length of time, by occaſionally pouring off the clear ſaturated liquor, and adding freſh water, obſerving to ſupply it conſtantly with as much of the powder as it will diſſolve.

The degree of cold at which water begins to freeze has been obſerved to vary much ;‡ but that it might be cooled twenty-two degrees below its freezing point was perfectly unknown to me until lately.

March 2, I filled the bulb of two thermometers, one with the pureſt rain water I could procure, the other with pump water ; the water was then made to boil in each, until one-third only remained: theſe were kept in a frigorific mixture, at the temperature of 10°, for a much longer time than I thought neceſſary to cool the water

* Wine may be cooled ſufficiently in the hotteſt weather of this climate, by immerſing the bottle containing it in water from a pump, obſerving that a pailful or two be drawn off firſt.

† I have uſed the ſame powder a dozen times; that is, I have evaporated the original powder for uſe *eleven* times.

‡ It is well known that water, in freezing by artificial cold, requires to be cooled ſeveral degrees below its freezing point ; commonly to 25°, or 26° ; but be it cooled ever ſo much below its freezing point, the inſtant it freezes, its temperature always becomes 32°.

water to the ſame temperature; and by repeated trials I found it was neceſſary to lower the temperature of the mixture to near 5°, to make the water in either of them freeze.

Theſe were likewiſe ſuſpended out of doors, cloſe to a thermometer, during the late froſt, and the water never obſerved frozen.

On March the 22d, at ſix in the morning, the water in each remained unfrozen, though the tubes were gently ſhaken, the thermometer ſtanding at that time at 23°.

There appeared to be little difference with reſpect to the degree of cold neceſſary to freeze the water, whether the tubes of the thermometers were open, or cloſed in vacuo (which was very nearly effected by ſuffering the water to boil up to the orifice of the tube, and then ſuddenly ſealing it) or not, but unboiled water in the ſame ſituation froze in a higher temperature.*

It

* Dr. Blagden found, that pure diſtilled water bore cooling more degrees below the freezing point than impure or hard pump water, that is nearly to 23°, whereas the latter could not be cooled below 25° or 24°, and that when the diſtilled water was deprived of its air by boiling, to near 20°; that turbid water could not be cooled much below its freezing point, and that *any thing* which leſſened the tranſparency of water (even boiling, if it became turbid, as is the caſe with hard ſpring water) made it freeze ſooner; the water uſed in theſe experiments

It is commonly ſuppoſed, I believe, that gentle agitation of any kind will diſpoſe water (cooled below its freezing point) to become ice; but I have repeatedly cooled rain water and pump water, boiled a long time, and unboiled, in open veſſels to 30°, or lower, and have conſtantly ſucceeded

ments was in a glaſs tumbler, immerſed in mixtures, and cooled very gradually.

Dr. BLAGDEN in theſe experiments refers to Dr. BLACK's, ſee page 22, and reconciles thoſe experiments with his own, by ſuppoſing that the water, which Dr. BLACK uſed, contained calcareous earth, held in ſolution by means of fixed air, as is the caſe with moſt kind of ſpring waters; this he obſerves being precipitated by boiling, will make the water turbid, and prevent, according to his own experiments, the water from cooling much below its freezing point.—Phil. Tranſ. 1788.

The circumſtance with me, of finding that water would bear cooling more than ſeven or eight degrees below its freezing point, was occaſioned by accident (the only diſcovery, in the courſe of theſe experiments, I am indebted to accident for). In order to try an experiment for freezing water upon the ſmalleſt ſcale, I immerſed a thermometer glaſs, with a ſmall quantity of water in its bulb, in a ſmall quantity of freezing mixture, expecting the water would freeze inſtantly; to my ſurprize it continued fluid, although I found by my thermometer it had been ſubjected to a cold of 15°. I at firſt imagined this circumſtance was owing to ſome impregnation of ſalt, or freezing mixture; but this not ſatisfying me, I took a freſh glaſs, put in ſome clean water, and repeated the experiment; when, finding the reſult the ſame, I purſued the experiment as above.

ſucceeded, after trying other kinds of agitation in vain, by ſtirring, or rather ſcraping gently, the bottom and ſides of the veſſel containing the water to be frozen, when after ſome ſhort time ſmall filaments of ice appeared, and by continuing this motion about every part of the veſſel, beneath the ſurface of the water, about two-thirds of the water commonly froze.

A ſlender pointed glaſs rod I uſed for this purpoſe.

I have the honour to be, &c.

RICHARD WALKER.

Oxford,
*March 27th*, 1788.

EXTRACT

From a ſecond Letter from MR. WALKER, to HENRY CAVENDISH, Eſq. dated *Oxford, May* 28, 1788.

A MORE intenſe cold I have found may be produced by a ſolution of ſalts in water in ſummer, than can be produced by a mixture of ſnow and ſalt in winter.

To rain water ſix drachms (by weight) I added ſix drachms of nitrous ammoniac, reduced to a very fine powder, which made the thermometer ſink from 50° (temperature of the materials) to 4°, then adding ſix drachms of mineral alkali very finely powdered, the thermometer ſunk to —7°, fifty-ſeven degrees.§

It is obſervable, that in the latter there are two cauſes concur in producing the effect, the *liquefaction* both of the ſnow and ſalt; but in the experiment juſt mentioned, the *liquefaction* of the ſalts only.

GLAUBER's ſalt, after it had given out its water of cryſtallization by expoſure to the atmoſphere, produced no change of temperature by

§ This frigorific mixture is by far the moſt powerful of any made by ſolution of ſalts in *water*. A mixture of ſnow and ſalt falls ſhort two degrees of this; that producing a cold only of —5°.

by folution in the diluted nitrous acid, but during folution in water produced heat, as did likewife the mineral alkali.

I have fince my laft feen FAHRENHEIT'S* Experiments on the cooling of water below its freezing point, related in vol. xxxiii, of the Philofophical Tranfactions.

* FAHRENHEIT cooled fome boiled rain water in a glafs globe, exhaufted of air to 15°, without freezing.—Phil. Tranf. vol. xxxiii. p. 81.

M. DE LUC cooled water, purged of air, to 14° ; but found that it froze inftantly, on breaking the bulb which contained it.—*Idées fur la Météorologie*, tom. ii. p. 205.

The cooling of water fo far below its freezing point, (as well as fome other curious facts, which incidentally occurred in the courfe of purfuing my fubject, on the means of producing cold), being only with me a matter of contingency, was not pufhed to the utmoft ; but I have reafon to believe, that water, may by the above management, be kept fluid at, or very near 0° : as it is, I have fhewn that *pure water* under certain circumftances will refift, without freezing, a degree of cold very rarely experienced in the fevereft winters of this climate.

EXPERIMENTS

# EXPERIMENTS
ON THE
# CONGELATION OF QUICKSILVER
IN
# ENGLAND:

*BY MR. RICHARD WALKER.*

In a Letter to HENRY CAVENDISH, Efq. F.R.S. and A.S.

PAPER III.
READ MAY 28, 1789.

SIR,

I NOW beg leave to trouble you with the particulars of my Experiments relative to the Congelation of Quickfilver, to which I fhall add an account of a few experiments, relating to the production of Artificial Cold, made fince my laft paper was written.

EXPERIMENT I. On December 28 laft, a favourable opportunity offered of beginning fome experiments on the Congelation of Quickfilver, which I was defirous of effecting completely; how far I have fucceeded will appear in the fequel.

For this purpofe I prepared a mixture of diluted vitriolic acid (reduced by water till its fpecific

ſpecific gravity was to that of water as 1, 559 6 to 1) and ſtrong fuming nitrous acid, of each equal parts. I preferred this mixture of acid becauſe it has been found by Mr. M'Nab, in Hudſon's Bay, to be capable of producing much greater cold, when the temperature of the materials at mixing is very low, than the nitrous acid alone; the former ſinking a thermometer to $-54\frac{1}{2}°$, the latter never lower than 46°.

A thermometer glaſs with its bulb only half filled with quickſilver was provided, this occurring to me as a convenient method of aſcertaining when the quickſilver was frozen; for if, after being ſubjected to the cold of a frigorific mixture, the thermometer glaſs ſhould be taken out and inverted, and the quickſilver found to remain completely ſuſpended in that half of the bulb now uppermoſt, no doubt can remain of the ſucceſs of the experiment; an hydrometer, with its lower bulb half an inch in diameter, and three fourths full of quickſilver, was likewiſe provided, in caſe any accident ſhould happen to the other.

It may be proper to premiſe here, that in all experiments of this kind I remove each veſſel, when the liquor it contains is ſufficiently cooled, out of the mixture in which it is immerſed for that purpoſe, immediately previous to adding the ſnow or ſalts with intention to generate a ſtill further increaſe of cold; and likewiſe prefer

adding

adding the ſnow or powdered ſalts to the liquor, inſtead of pouring the liquor upon theſe; it is neceſſary alſo to ſtir about the ſnow or ſalts, whilſt cooling in a frigorific mixture, from time to time, otherwiſe it will freeze into a hard maſs, and fruſtrate the experiment.

A half pint glaſs tumbler, containing two ounces and a half of the above-mentioned diluted mixture of acids, being immerſed in mixtures of nitrous acid and ſnow, until the liquor it contained was cooled to — 30°, was removed out of the mixture and placed upon a table; ſnow, likewiſe previouſly cooled in a frigorific mixture to — 15°, was added by degrees to the liquor in the tumbler, and the mixture kept ſtirring until a mercurial thermometer ſunk to —60°, where it remained ſtationary; the hydrometer was then immerſed in the mixture (the thermometer glaſs having been broken in the courſe of the experiment), and ſtirred about in it for a ſtort time, and on taking the hydrometer out, and gently ſhaking it, I perceived the mercury had already acquired the conſiſtence of an amalgam, and after immerſing it again for a few minutes, and then taking out and inverting it, I was gratified for the firſt time with the ſight of quickſilver in a ſtate of perfect congelation.

I applied my hand to the inverted glaſs bulb; this ſoon looſened the ſolid quickſilver, which,

on ſhaking the hydrometer, was diſtinctly heard to knock with force againſt the glaſs; it was then immerſed a ſecond time, and when taken out was found adhering to the glaſs as before.

I now inverted the glaſs again, and kept it in that ſituation until the whole of the quickſilver melted, and dropped down globule after globule into the ſtem of the hydrometer.

The interval of time from taking the quickſilver out of the frigorific mixture in a ſolid ſtate, the laſt time, to its perfect liquefaction, was not noticed; but, upon recollection immediately afterwards, was ſuppoſed to be not leſs than three or four minutes. In a ſucceeding experiment this circumſtance was attended to, and the frozen quickſilver, weighing ſeven ſcruples, was not entirely melted under ſeven minutes, the temperature of the air at the time being 30°.

The experiment which follows I conſider the moſt extraordinary, becauſe it proves beyond a doubt, that quickſilver may be frozen not only here in ſummer, but even in the hotteſt climate, at any ſeaſon of the year, by a combination of frigorific mixtures, in the way deſcribed in the Philoſophical Tranſactions, vol. lxxvii, p. 285.* in which attempt to freeze quickſilver made April 20th, 1787, the temperature of the air and

* See page 7.

and materials being $45^{\circ}$, I certainly reached (without the affiftance of fnow or ice) the point of mercurial congelation; but had then no fatiffactory proof that any part of the quickfilver was abfolutely congealed.

Experiment II. On December 30, three ounces of a mixture compofed of ftrong fuming nitrous acid, two parts, and ftrong vitriolic acid and water, each one part, were cooled in a half pint tumbler immerfed in a frigorific mixture, till the temperature of the diluted mixture of acids was reduced to $-30^{\circ}$. The tumbler was then removed out of the mixture, and Glauber's falt, in very fine powder, previoufly cooled to $-14^{\circ}$ by a frigorific mixture, added by degrees to the liquor in the tumbler, ftirring it together until the mercury in the thermometer funk to $-54^{\circ}$. The hydrometer ufed in the former experiment, with its lower bulb three-fourths full of quickfilver, was now immerfed and ftirred about in the mixture for a few minutes, when on taking it out, and inverting it, I had the fatisfaction to find the fame proof of the quickfilver being frozen as in the former inftance. It was immediately fhewn to the Gentlemen prefent, who expreffed likewife their entire fatisfaction.

Nearly four ounces of the powdered falt was

 added;

added; but I believe, ſome was added after the greateſt effect was produced.

I had no nitrous ammoniac by me, otherwiſe I ſhould have uſed upon this occaſion, inſtead of Glauber's ſalt alone, a mixture of theſe two ſalts in powder, in the proportion of ſeven parts of the former to eight of the latter.

The temperature of the room in which theſe experiments were made was 30° each time, and the quickſilver taken from a jar containing ſeveral pounds.

Experiment III. By an experiment made purpoſely on January 10th laſt, at which Dr. Bourne was preſent, I have found that quickſilver may be congealed tolerably hard, by adding freſh fallen ſnow, at the temperature of 32° to ſtrong fuming nitrous acid, previouſly cooled to between — 25° and — 30°, which may be very eaſily and quickly effected by immerſing the veſſel containing the acid in a mixture of ſnow and nitrous acid.

I uſe the *fuming* nitrous acid upon all occaſions, becauſe that does not require to be diluted, cold being immediately produced on the ſmalleſt addition of ſnow.*

Experiment

* On the firſt addition of ſnow to ſtrong vitriolic acid, or *dephlogiſticated* nitrous acid, heat is produced; becauſe the cold

Experiment IV. On January 12, by particular requeſt, I repeated the experiment of freezing quickſilver at the Anatomy School in Chriſt Church, in the preſence of the Honourable Mr. Wenman, the Reverend Dr. Hoare, Dr. Sibthorpe, Junior, the Reverend Mr. Jackson, of Chriſt Church, and Mr. Wood, of this place, a Gentleman well known for his ingenuity in mechanics.

For this purpoſe were provided a ſpirit thermometer graduated very low, and a mercurial thermometer graduated to $-76°$, two thermometer glaſſes with bulbs very near, if not quite, an inch in diameter each, one filled with mercury nearly to the orifice of the tube, which was left open, the other with its bulb half filled, and an hydrometer with its lower bulb (conſiderably leſs than either of the others), likewiſe half filled with mercury; the temperature of the room at this time 28°.

A pan, containing nine ounces of the mixture of acids prepared as in the firſt experiment, was placed in a larger pan, containing nitrous acid, and this, in a frigorific mixture of nitrous acid and ſnow, contained in another pan much larger.

When

cold which would be produced, by the ſnow diſſolving, is *at firſt* more than counteracted by the diſpoſition of the diſſolved ſnow, in uniting with the acid, to generate heat.

When the nitrous acid in the ſecond pan was cooled, by this mixture, to —18°, and the mixed acids in the ſmalleſt pan nearly as much, ſnow, at ſomewhat between 20° and 25°, the temperature of the open air at that time, was added to the nitrous acid in the ſecond pan, until the ſpirit thermometer ſunk to near — 43°; then the thermometer, with its bulb half filled, was immerſed a ſufficient time, and, when taken out, the quickſilver in it was found frozen, and adhering to the glaſs.

The pan containing the mixed acids, and which had been removed whilſt the ſnow was added to make the ſecond mixture, was now replaced in it, in order to be cooled; and when the mixture of acids was reduced to the temperature of —34°, ſnow, previouſly cooled to —18°, was added, keeping the mixture ſtirred until the mercurial thermometer ſunk to — 60°; its temperature, by the ſpirit thermometer, was then found to be —51°.*

The three glaſſes, containing the quickſilver to be frozen, were now immerſed in this mixture

* Quickſilver having been ſubjected in the inſtance which follows, to a greater degree of cold than hitherto, as will appear by examining the table; the very accurate deſcription given of its appearance in a ſolid ſtate, (for which I am obliged to a gentleman preſent, well ſkilled in mineralogy), may conſequently be more intereſting.

ture, and having been moved about in it for a confiderable time, during which the fpirit thermometer rofe fcarcely one degree, were then feverally taken out, and examined.

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When the freezing mixture was fuppofed to have produced its effect, the bulb, which was completely filled, was taken out, and broken on a flat ftone, by a moderate ftroke or two with an iron hammer.

This bulb was eleven or twelve lines in diameter.

The folid mercury was feparated into feveral fharp and brilliant fragments, fome of which bore handling for a fhort time before they returned to a fluid form. One mafs, larger than the reft, confifting of nearly one third of the whole ball, afforded the beautiful appearance of flat plates, converging towards a center.

Each of thefe plates was about a line in breadth, at the external furface of the ball, becoming narrow as it fhot inwards. Thefe facets lay in very different planes, as is common in the fracture of any cryftallized ball, whether of a brittle metal or of the earths, as in balls of calcareous ftalactite. The folid brittle mercury, in the prefent inftance, bore a very exact refemblance, both in colour and plated ftructure, to fulphurated antimony, and efpecially to the radiated

radiated ſpecimens from Auvergne, before they are at all tarniſhed.

Inſtead of a ſolid center to this ball, it ſeemed as if there had been a central cavity, of about two lines in diameter, a conſiderable portion of which was evident in the fragment juſt deſcribed, at that part to which the radii converged. It is indeed poſſible, that this may have been merely the receptacle of ſome part of the mercury remaining fluid at the center. The hollow within was ſhining, but its edges were neither ſoft nor mouldering; on the contrary, they were ſharp and well defined; nor was the brilliancy of the radii attributable to any exudation of mercury, as from an amalgam.

In the two ſmaller bulbs, which were only half filled, the mercury preſerved its uſual luſtre on the ſurface, in contact with the glaſs, as well as on that ſurface which it had acquired in becoming ſolid. The latter was occupied by a conical depreſſion, the gradations of which were marked by concentric lines.

One of theſe hemiſpheres was ſtruck with a hammer, as in the former inſtance, but was rather flattened and cruſhed than broken. The other, on being divided with a ſharp chiſſel, ſhewed a metallic ſplendour on its cut ſurface, but not equalling the poliſh of a globule of fluid mercury.

Thirteen

Thirteen ounces of ſnow, in the whole, were found to have been added to the mixed acids; but ſome was added, to lower its temperature, after the glaſſes containing the mercury were taken out, and the ſpirit thermometer had riſen a few degrees.

This was a day remarkably favourable for ſuch an experiment. My thermometer, expoſed to the open air, ſtood, at three quarters paſt eight this morning, at 6°,* which is a very extraordinary degree of cold here; but this experiment was not begun till noon.

EXPERIMENT V. On Jan. 14, I froze quickſilver at the Anatomy School again, in the preſence of the Rev. the Dean of Chriſt Church, and the Rev. Dr. HORNSBY.

Four ounces now, of the mixture of acids, prepared as in the firſt experiment, were cooled in a tumbler to —20°, which required ſomewhat more than an equal weight of ſnow, cooled nearly to the ſame temperature, to produce the greateſt effect.

This

* In the ſevere froſt of 1739, the loweſt degree to which the thermometer ſunk was 12½, according to the obſervations of Lord CHARLES CAVENDISH.

Mr. WHITEHURST obſerved the thermometer, at nearly one degree below 0, at Derby, on January 18, 1767, which, perhaps, he ſays, is the greateſt cold ever obſerved in England.—Phil. Tranſ. for 1767.

This was ſomewhat leſs than in the laſt experiment, the ſpirit thermometer ſinking no lower than — 46°, owing chiefly to the weather having become much warmer, the temperature of the open air being now 36°.

The mercurial thermometer, immerſed in this mixture, ſunk to —55°, where it became ſtationary; then two thermometer glaſſes, one half filled with mercury, and the other filled to a conſiderable height up the tube, after being immerſed ſome time, were examined.

Upon breaking the ſhell of glaſs from the former of theſe, the quickſilver was found in a perfectly ſolid ſtate; but its upper ſurface, which was highly poliſhed, and of the colour of fluid quickſilver, inſtead of being only ſlightly depreſſed, has had been ſeen in every other inſtance which afforded an opportunity for inſpection, now formed a perfectly inverted hollow cone.

This great depreſſion, as well as the concentric circles mentioned in a former inſtance, I ſuppoſe, might be owing not entirely to the contraction of the quickſilver in becoming ſolid, but partly to a rotatory motion accidentally given to it whilſt congealing.

The ſolid quickſilver was beaten out, but having been ſuffered to lie ſometime on the table for inſpection, very quickly melted into liquid globules. The flexibility of ſolid quickſilver was

was clearly to be obſervéd in this beautiful ſpecimen; for the external ſurface, particularly the upper thin rim of the concave part, was evidently bent by the firſt gentle ſtroke of the hammer.

The globe of quickſilver in the other glaſs, which was very ſmall, exhibited nearly the ſame phenomena, as in the inſtances before mentioned.

It happened in theſe experiments of mine, contrary to what has generally occured to others, that the mercury never ſunk lower than — 60°, ſeldom ſo low, in the thermometer, and but little below the point of mercurial congelation in the tubes of the thermometer glaſſes filled nearly up to the orifice, with a view to ſhew the contraction of quickſilver in becoming ſolid by its great deſcent in the tube.

Reflecting upon this circumſtance afterwards, it occurred to me, that the further deſcent of the mercury in theſe experiments was prevented, not ſolely by the mercury freezing in the tube, the cauſe commonly aſſigned, but rather by the quick formation of a ſpherical ſhell of ſolid mercury within the bulb, by the ſudden generation of cold.*

EXPERIMENT

* If, therefore, it be required to ſhew the utmoſt contraction quickſilver is capable of, the cold, neceſſary to freeze it, ſhould be produced very *gradually*; and the whole of the bulb, containing it, ſhould not be completely immerſed, till toward the concluſion of the experiment.

Experiment VI. Dr. Beddoes expreſſing a deſire to exhibit ſolid quickſilver at his lecture before his claſs, I undertook to freeze ſome at the Laboratory on March 12, laſt, and now reſolved to ſatisfy myſelf reſpecting the cauſe which prevented the lower deſcent of the mercury in my former experiments.

In this, as well as the former, the mercury in a thermometer graduated to — 60°, and likewiſe in a thermometer glaſs, filled nearly to the orifice, which lengthened its ſcale to near — 250°, ſunk only a few degrees below the point of mercurial congelation, and then remained ſtationary. After waiting ſometime, I took the thermometer out of the mixture, and obſerved the bulb apparently full, and the ſhort thread of mercury above unbroken. I now graſped the lower part of the tube with my hand a few ſeconds, reſting it upon the upper part of the bulb, and, upon taking it away, I found that the whole of the quickſilver had ſubſided into the bulb, which it did not now quite fill, a ſmall ſpace at the top of the bulb remaining empty. I then took out the thermometer glaſs, and applied my hand to the tube; but the mercury remained ſtationary until I ſunk my hand ſo as to communicate heat to that part of the bulb which is immediately connected with the tube, when the thread of mercury dropped entirely into the bulb.

It

It was now immerfed again for a fhort time, then taken out, and the fhell of glafs beaten off, which expofed a globe of folid quickfilver nearly an inch in diameter.

This bore feveral very fmart ftrokes with a hammer before it began to liquify, but was not perfectly malleable.

In the courfe of thefe experiments feveral fragments of folid mercury were thrown into mercury in its ordinary liquid ftate, and were found to fink with celerity.*

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In continuing my refearches refpecting the means of producing artificial cold, I have found that phofphorated foda produces rather more cold by folution in the diluted nitrous acid than GLAUBER's falt.

At the temperature of 50°, four parts of the diluted nitrous acid (prepared by mixing ftrong nitrous acid with half its weight of water) required

* The contraction of quickfilver in freezing, fhews that its fpecific gravity is increafed in becoming folid.

quired eight parts of that neutral falt in fine powder to be added, in order to caufe the thermometer to fink to — 6°; and again, by the addition of five parts of nitrous ammoniac in fine powder, the thermometer funk fo low as — 16°, in the whole fixty-fix degrees.

A mixture of this kind made the thermometer fink from 80°, (the temperature of the materials before mixing) to 0°.

I was directed to the trial of this falt by the like remarkable fenfation of coldnefs without pungency, which, with its other fimilar properties to ice,* firft induced me, whilft purfuing the fubject of cold, to try the effect of diffolving the Glauber's falt in the mineral acids.

Equal quantities by weight of phofphorated foda and Glauber's falt, were evaporated feparately over a gentle fire, until each was reduced to a perfectly dry powder. I then weighed them, and found the refiduum of the phofphorated foda fomewhat lighter than that of the Glauber's falt; from whence it is probable the former contains the greateft quantity of water of cryftallization.

I have

* "Ice is a true cryftallization."—Macquer's Chem. Dict.

I have found, that each of the neutral ſalts which produce any remarkable degree of cold by ſolution in the mineral acids, viz. phoſphorated ſoda, GLAUBER's ſalt and Epſom ſalt, loſe this property entirely, when deprived by any means of their water of cryſtallization.

By a trial made with great accuracy, I find, that even the mixture compoſed of diluted vitriolic acid and GLAUBER's ſalt is adequate to any uſeful purpoſe that may be required in the hotteſt country; for, by adding eleven parts of the ſalt in fine powder, to eight parts of the vitriolic acid, diluted with an equal weight of water, the thermometer ſunk from 80°, the mean temperature of the hotteſt climate, and to which theſe materials were purpoſely heated before mixing, to rather below 20°.

GLAUBER's ſalt added to the marine acid undiluted, produces very nearly as great a degree of cold as when mixed with the diluted nitrous acid. At the temperature of 50°, two parts of the acid require three parts of the ſalt in fine powder, which will ſink the thermometer to 0°; and if three parts of a mixed powder, containing equal parts of ſal ammoniac and nitre be added afterwards, the cold of the mixture will be increaſed a few degrees more.

The

The frigorific mixture above defcribed, compofed of phofphorated foda and nitrous ammoniac, diffolved in the diluted nitrous acid, being the moft powerful, it will probably be found moft convenient for freezing quickfilver, when fnow is not to be procured.

The materials for this purpofe may be previoufly cooled in mixtures made of marine acid, with GLAUBER's falt, fal ammoniac, and nitre, in the proportions mentioned above, this being much cheaper than thofe made with diluted nitrous acid, and very nearly equal in effect.

In my laft paper I mentioned a freezing mixture made by diffolving a powder compofed of equal parts of fal ammoniac and nitre in water, and therein directed fix parts of the mixed powder to be added to eight parts of water; but I have found fince, that the beft proportions are five parts of the former to eight of the latter, by which I have funk the thermometer from 50° to 11°.

Having now profecuted my fubject relative to mixtures for generating artificial cold without the ufe of *ice*, from a poffible method propofed by Dr. WATSON, (Effays, vol. iii, p. 139.) for freezing

freezing water in ſummer in this climate, and carried it on to a certain method of freezing, not only water, but even quickſilver, in the hotteſt climate, I now intend to take my leave of it.

I have the honour to be, &c.

RICHARD WALKER.

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Suppoſing it might be uſeful to give ſome account of the ſubject on which this paper is written, I thought I could not do better than preſent my readers with an Epitome of Dr. BLAGDEN's "Hiſtory of the Congelation of Quickſilver," (Phil. Tranſ. 1783): I have, therefore, given the different inſtances therein mentioned, produced as well by natural as artificial cold, with the phenomena attending each, *condenſed* into the form of the table annexed.

N. B. The phenomena in each inſtance, are connected with the correſponding table on the oppoſite page, *ſimilar* figures of references.

# QUICKSILVER FROZEN BY ARTIFICIAL COLD.

| | *Where.* | *When.* | *By Whom.* | *Descent of Merc. Therm.* | *Degree of Cold Produced, as appeared by a Spirit Thermometer.* | *Temp. of Air.* | *Temp. of Materials at mixing.* |
|---|---|---|---|---|---|---|---|
| 1. | PETERSBURGH | Dec. 14, 1759, O.S. | Professor BRAUN | —69° | | —34° | —34° |
| 2. | HUDSON'S BAY | Jan. 19, 1775 | Mr. HUTCHINS | —430° | | —28° | —28° |
| 3. | ROTTERDAM. | Jan. 28, 1776 | Dr. LAMBERT BICKER | —94° | | 2° | 2° |
| 4. | HUDSON'S BAY | Frequently 1782 | Mr. HUTCHINS | —450° | —46° | —35° | —35° |
| 5. | PETERSBURGH | Frequently 1783 | Dr. GUTHRIE | —305° into bulb | | —13° | previously —13° |
| 6. | HAMPSTEAD | Feb. 26, 1783 | H. CAVENDISH, Esq. | —110° | —45° | 22° | cooled to near 0° |

The three following instances are likewise mentioned in the above paper, but omitted in this table. M. BLUMENBACH's experiment at Gottingen, Jan. 11, 1774; Dr. FOTHERGILL's at Northampton, Jan. 30, 1776; and M. CAZALET's at Bourdeaux.

In the first, a mixture of snow and powdered sal ammoniac was used to produce the effect, the temperature of air and materials being at— 10°; and the Quicksilver is said to have been frozen solid; how this could have been effected is wonderful, but certainly not by the cold generated by those materials.*

Dr. FOTHERGILL in his experiment, says, he observed a film upon the surface of some Quicksilver immersed in a frigorific mixture, made of strong vitriolic acid and snow, temperature of air and materials at 9°; but the cold produced by a mixture of this kind made at that temperature would certainly be less than —39°; even if the vitriolic acid had been properly diluted.

M. CAZALET's experiment was made in a climate milder than England, in the month of September, and his mixture made of powdered ice, and concentrated nitrous acid, in a vessel with its bottom full of holes, that the ice as fast as it dissolved might escape and leave room for constant additions of fresh materials, by which it is said, by the time 120 pounds of ice were consumed, some Quicksilver in glass tubes, immersed in this mixture, when examined, was found congealed, and resembled silver threads or wires:—the temperature of the air at the time is not noticed, neither is a thermomometer mentioned to have been used.

A similar method of increasing cold, without previously cooling the materials for one mixture by immersing them in another, occurred to me long since; accordingly I tried the effect of such a method, by each of the frigorific mixtures I have had occasion to use, with the difference only of pouring off occasionally the clear liquor from the undissolved salts at the bottom, and adding from time to time more of the diluted acid, or water, and powdered salts; but was never able by this means to produce greater cold, than is generated almost instantaneously, by mixing together suddenly, the same materials, in their proper proportions.

* This gentleman, (M. BLUMENBACH,) whom I have seen since this paper was written, acknowledged to me that he was deceived in this experiment.

1. This effect was produced by a mixture of aqua fortis and pounded ice, and the Quickfilver in the thermometer not examined;* but in fucceffive experiments the fame feafon, by the ufe of fnow, which produced much greater cold, and breaking his thermometer, he afcertained what had been long fufpected, that Quickfilver, in a fufficient degree of cold, is a folid metal. The greateft defcent of the Quickfilver, he obferved in his thermometer, and the bulb not broken was —556°, when the Quickfilver in it upon examination was found perfectly folid, from which he erroneoufly concluded that this was the freezing point of Quickfilver. He found to effect the congelation completely, it was neceffary the temperature of air fhould not be warmer than —10°, though fome commencement of congelation might be perceived when the temperature of the air and materials was at 2°. He likewife, as others have done fince, obferved that Quickfilver, under certain circumftances, cryftallizes in becoming folid, and poffeffes confiderable ductility though not perfectly malleable.

2. The external coat or fhell of the Quickfilver found, upon breaking the bulb, in a folid ftate; but internal part perfectly fluid.

3. Found upon breaking the bulb the outer part of the Quickfilver thickened to an amalgam; but the inner part perfectly fluid.

4. Point of mercurial congelation afcertained to be at —39°,† but would bear cooling a few degrees lower without congealing, to which it rofe again like water, &c. on freezing; confequently the further defcent of the Quickfilver in the thermometer, owing to the contraction of Quickfilver, in changing from a fluid to a folid ftate, its fpecific gravity being thereby increafed.

During the winter of 1781—2, Mr. HUTCHINS, by the direction of the Royal Society, and with an apparatus contrived for the purpofe by Mr. CAVENDISH, afcertained, by a number of decifive experiments, the precife point as above-mentioned at which Quickfilver freezes; or rather, confidering it now as a metal, that temperature at which it melts. The apparatus for this purpofe confifted of a glafs cylinder, containing fome Quickfilver, in which the bulb with part of the tube of the thermometer was included; thus, when the Quickfilver in the cylinder was frozen, the thermometer having its bulb immerfed in it, indicated its temperature. See Mr. HUTCHINS's "Experiments for afcertaining the point of Mercurial Congelation," with Mr. CAVENDISH's Obfervations on the fame. Phil. Tranf. 1783.

5. Quickfilver congealed.

6. Quickfilver in the bulb of the thermometer not examined, but muft have been partially congealed.

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* PROFESSOR BRAUN, it feems, had no other object in view at the commencement of thefe experiments, than merely to produce a greater degree of cold than FAHRENHEIT had done before him, who funk his thermometer to —40, and was led to the ufe of fnow, in the profecution of his experiments, not from preference, but becaufe all his ice was confumed.

† The point of mercurial congelation, according to the thermometer which Mr. HUTCHINS ufed, was —40; but on comparing this with a ftandard thermometer, it was found to ftand one degree and one-third *too low*; which fixes the precife point at which Quickfilver freezes, at — 38° $\frac{2}{3}$, or in whole numbers — 39°.

Mr. HUTCHINS likewife embraced an opportunity which prefented at Hudfon's Bay, Jan. 26, 1782, of confirming the above, by an obfervation with the *natural cold*.

Quickfilver, whilft it retains its fluidity, contracting uniformly in proportion to the temperature to which it is fubjected, is a juft meafure of heat; but its contraction as foon as it begins to freeze, being irregular, and not depending on temperature, it then ceafes to be a meafure of heat; confequently a *mercurial thermometer* is ufelefs at a temperature lower than — 39, and it then becomes neceffary to ufe a thermometer of rectified fpirit of wine in its ftead.

Quickfilver, in becoming folid, contracts about 1-23d of its whole bulk..

## QUICKSILVER FROZEN BY NATURAL COLD.

| *Where.* | *When.* | *By Whom. obſerved.* | *Deſcent of Merc. Therm.* |
|---|---|---|---|
| 1. YENISEISK, SIBERIA, N. Lat. $58\frac{1}{2}$, E. Long. 92, and ſeveral other places near, in 1737, 1738, 1742. | Frequently 1734 | Dr. GMELIN | — 120 |
| 2. YAKUTSK, SIBERIA, N. Lat. 62, E. Long. 130. | 1736 | M. de L'ISLE de la CROYERE | |
| 3. QUEBEC, N. L. 47, W. L. 74. | 1743—49 | M. GAUTIER | into bulb |
| 4. LAPLAND, at different places ſituated between 60° and 70° N. and 21° and 28° E. | Jan. 23, 1760 | M. ANDREW HELLANT | — 238° into bulb |
| 5. SOLIKAMSK, SIBERIA, $59\frac{1}{2}$ N. 57 E. | 1761 | Abbé CHAPPE D'AUTEROCHE | — 124° |
| 6. KRASNOYARSK, Siberia, $56\frac{1}{2}$ N. 93 E. | Dec. 6, 1772 | M. PALLAS | — 70° into bulb |
| 7. IRKUTSK, SIBERIA, 52 N. 104 E. | Dec. 9, 1772 | Gov. Von BRILL | |
| 8. HUDSON'S BAY, Albany Fort, 52 N. 82 W. York Fort, 58 N. 92 W. | 1778 | Mr. HUTCHINS | — 490° |
| 9. VYTEGRA, RUSSIA, 61° N. 36° E. | Jan. 5, 1780 | M. Von ELTERLEIN | — 57° |
| 10. JEMTLAND, SWEDEN, $63\frac{1}{2}$ N. 15 E. | Jan. 1, 1782 | Mr. J. TÖRNSTEN | — 130 into bulb |

From obfervations of late, it appears, that a degree of natural cold fufficiently intenfe to freeze Quickfilver, happens not unfrequently in the winters of rigorous climates; in Hudfon's Bay the fpirit thermometer has once been obferved fo low as — 50°.

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## PHENOMENA.

1. Not fufpected then, but known fince from inference to have been partially congealed.

2. Quickfilver juftly fufpected to be congealed in the tube of a barometer. "M. De L'Isle de la Croyere, (Dr. Blagden obferves,) was probably the firft perfon upon earth who faw Quickfilver reduced to a folid form by cold, and ventured to credit the teftimony of his fenfes."

3. Quickfilver partially congealed.

4. Not fufpected then, but muft have been partially congealed.

5. Quickfilver congealed.

6. "I put four ounces of Mercury in a bowl, the whole was condenfed by cold into a foft mafs very much like tin, and more flexible than lead; but upon being bent fhort was found more brittle than tin, and when hammered out thin, it feemed fomewhat granulated."

7. Mercury obferved to be congealed.

8. Mercury obferved congealed frequently, in the winters preceding, and fubfequent to this.

9. "Three ounces of Mercury fet out in a tea-cup was frozen folid, looking like caft lead, with a confiderable depreffion in the middle; on attempting to loofen it with a knife, fhavings were raifed, which remained fticking up,—"When handled, with intention to bend it, the lump broke." With thermometer at — 39, the Mercury became fluid."

10. Mercury not examined.

N. B. The Temperature of the air, in the above obfervations on Quickfilver frozen by natural cold, was noticed only in one inftance, viz. by Mr. Hutchins, in Hudfon's Bay, when the fpirit thermometer ftood at — 46°.

That cold is produced by diffolving fnow in each of the mineral acids, was I believe, firft difcovered by BOYLE, *fee Boyle's works, vol.* ii, *p.* 509, who likewife obferves, *page* 510, that of thefe, the greateft cold is produced by diffolving fnow in *ftrong fpirit of Nitre*: he likewife attempted to freeze Quickfilver, *page* 517, by artificial, as well as natural cold. Whence it is probable, if BOYLE had lived in a climate more favourable to his purpofe than England; the difcovery, that Quickfilver in a fufficient degree of cold becomes a folid metal might have been anticipated half a century.

NOTE. In a well adjufted mercurial thermometer, it may be fafely concluded, that congelation of the included Quickfilver has *commenced*, as foon as the thermometer reaches $-43°$; I have commonly found this to happen at $-40°$.

# OBSERVATIONS

ON THE

BEST METHODS OF

# PRODUCING ARTIFICIAL COLD;

*BY MR. RICHARD WALKER.*

Communicated by MARTIN WALL, M.D. F.R.S.

PAPER IV.

READ MAY 14, 1795.

HAVING already inveſtigated the means of producing artificial cold, and at the concluſion of my laſt paper (on the congelation of quickſilver) diſmiſſed *that part* of the ſubject, the beſt method of making uſe of thoſe means naturally becomes a deſideratum; to that therefore I have lately given my attention, and flatter myſelf that the following obſervations may be conſidered as an uſeful appendix to my former papers.

The freezing point of quickſilver being now as determined a point on the ſcale of a thermometer, *viz.* —39°, as the freezing point of water; and as this metal, exhibited in its ſolid ſtate, affords

fords an interefting as well as curious phenomenon, I fhall apply what I have to fay principally to that object.

Frequent occafions having occurred to me of obferving the fuperiority of fnow, in experiments of this kind, to falts even in their fitteft ftate, that is, frefh cryftallized, and reduced to very fine powder, I refolved upon adopting a kind of artificial fnow.

The firft method which naturally prefented itfelf, was by condenfing fteam into hoar froft; this anfwered the purpofe, as might be expected, exceedingly well; but the difficulty and expence of materials in collecting a fufficient quantity, determined me to relinquifh this mode for another, by which I can eafily and expeditioufly procure ice in the fitteft form for experiments of this kind: the method I mean, is by firft freezing water in a tube, and afterwards grinding it into very fine powder.

Thus poffeffed of the power of making ice, and afterwards reducing it to a kind of fnow, the congelation of quickfilver becomes a very eafy and certain procefs; for by the ufe of a very fimple apparatus (fee the plate, fig. 6.) quickfilver may be frozen perfectly folid in a few minutes, wherever the temperature of the air

does

does not exced 85°, thus: one ounce of nitrous acid is to be poured into the tube *b* of the veſſel, obſerving not to wet the ſide of the tube above with it; a circular piece of writing paper of a proper ſize is to be placed over the acid, reſting upon the ſhoulder of the tube, and the paper bruſhed over with ſome melted white wax; thus prepared, the veſſel is to be inverted, and filled with a mixture of diluted nitrous acid, phoſphorated ſoda, and nitrous ammoniac, in proper proportions for this * temperature, and tied over ſecurely, firſt with waxed paper, and upon that a wet bladder.

The veſſel being then turned upright, and placed in a ſhallow veſſel, *viz.* a ſaucer or plate, an ounce and a half of rain or diſtilled water is to be poured into the tube, which is to be covered with a ſtopper or cork; and, as ſoon as frozen ſolid, ground to fine powder, an aſſiſtant holding it firmly and ſteadily the while; obſerving occaſionally to work the inſtrument in different directions up and down, that no lumps may be formed.

When the whole of the ice is thus reduced to powder, and the lumps, if any broken, the frigorific

* I have, by a very accurate preparation of this mixture, ſunk a thermometer from 85° (temperature of the veſſel and materials) to 2°.

For the proportions of the materials to be uſed at any given temperature, *ſee the Table*, and the directions which follow it.

gorific mixtures is to be let out quickly, by cutting or untying the ſtring, and removing the bladder, &c. which confines it; a communication made, by forcing a rod of glaſs or wood through the partition; and the whole mixed expeditiouſly to together.

In this climate, a mixture much leſs expenſive will be ſufficient, *viz.* that compoſed of diluted nitrous acid, Glauber's ſalt, ſal ammoniac, and nitre; a mixture of this kind ſinking a thermometer in the warmeſt weather to near 0°.

At the temperature of 70°, or a little higher the quantity of diluted nitrous acid may be about one-fourth leſs than is mentioned in the table, for 50°.

Theſe methods are the moſt expeditious, and attended with the leaſt trouble; but as ice may be uſed with equal certainty, and with much leſs expence, I ſhall give a particular detail of an experiment made with the uſe of it; firſt mentioning a preparatory experiment, to which I was immediately led by the recollection that Sir Charles Blagden, in his paper "On the Point of Congelation," (Phil. Tranſ. vol. lxxviii.) had found that ſal ammoniac and common ſalt, mixed with ſnow, produced a cold of —12°, whereas the latter uſed alone with ſnow produces only —5°.

I uſed

I uſed a mixed powder of equal parts of common ſal ammoniac and nitre with the common ſalt, by which the thermometer ſunk to $-18°$; and when I uſed nitrous ammoniac with common ſalt, to $-25°$; this cold I could not increaſe by the addition of any other ſalts, nor could I equal it by any other combination of ſalts: thoſe I tried were GLAUBER's ſalt, ſalt of tartar, ſoda, and Epſom ſalt: by ſeveral trials, I found the beſt proportions to be, ſnow or pounded ice twelve parts, common ſalt five parts, and of nitrous ammoniac, or a powder of equal parts ſal ammoniac and nitre mixed, five parts; or *one third* of common ſalt, when I uſed that *alone* with ſnow or pounded ice

My apparatus then (Dec. 28th laſt) conſiſted of two veſſels (fig. 1 and 9), an inſtrument, (fig. 3) to grind or rather ſcrape the ice to powder; a kind of ſpatula (I uſe a marrow ſpoon) to ſtir the powder occaſionally; a thermometer (fig. 4); and a ſmall thermometer glaſs, with the bulb three-fourths full of quickſilver (fig. 5).

I filled the veſſel, (fig. 1), holding when inverted, two pints, *ſtratum ſuper ſtratum*, with pounded ice, common ſalt, and a powder conſiſting of equal parts, ſal ammoniac and nitre mixed together; by firſt putting in ſix ounces of pounded ice, then two ounces and a half of common

common ſalt, and, after ſtirring theſe well together, two ounces and a half of the mixed ſalts, mixing the whole well together; this was repeated in the ſame manner until the veſſel was quite full; it was then tied over ſecurely with a wet bladder, turned upright, and one ounce and a half of rain water poured into the tube through a funnel, the tube covered with a cork, and the veſſel left undiſturbed till the water was frozen perfectly ſolid.

The inſtrument for grinding it was then put in to acquire cold, whilſt the veſſel. fig. 9, holding, when inverted a pint, was filled in the ſame manner, with the ſame proportions of materials, a bladder tied over it, ſet upright, and one ounce of fuming nitrous acid poured into the glaſs to be cooled.

The ice was then ground to powder, and when finiſhed, the nitrous acid being found to have acquired a ſufficient degree of cold, viz. —13°, the frigorific mixture of ice and ſalts was let out of the veſſel which contained the nitrous acid; and the powdered ice (ſtill ſurrounded by its frigorific mixture) added to the acid as quick as poſſible; when the thermometer ſunk to near —50°, and the mixture ſoon froze the quickſilver in the glaſs bulb.

In this experiment, 18 minutes were required to freeze the water perfectly ſolid; and 15 to reduce

reduce the ice, by moderate labour, to very fine powder. The experiment was over in 55 minutes; and the temperature of the preparatory cooling mixture then found to be $-10°$.

I had a fpirit thermometer by me, but a mercurial thermometer being much more fenfible, and confequently defcending much quicker, I prefer it in experiments made merely to freeze quickfilver; knowing from experience how the congelation is going on, from the irregular defcent of the mercury, when a few degrees below its freezing point; and from having ufually found that the quickfilver in the thermometer glafs begins to freeze as foon as the mercurial thermometer reaches $-40°$.

Whenever I have occafion to ufe ice in fummer for this purpofe, I ufually pound together, firft fome ice and falt in a ftone mortar, about two parts of the former to one of the latter; throw this away, and wipe the peftle and mortar perfectly dry; the mortar being thus cooled, the ice may afterwards be pounded fmall without melting.

And as a mixture made of fnow, or ice in powder, and falts, does not give out its greateft cold till it is become partially liquid, by the action of the ice and falts on each other; it is neceffary that the whole be ftirred well together, till it is

is become of an uniformly moiſt *pulpy* conſiſtence, eſpecially ſince in becoming liquid the mixture ſhrinks ſo much, that if this be not attended to, the veſſel will not be near full, and conſequently the upper part of the tube not ſurrounded, as it ought to be, by the frigorific mixture. The diſſolution of the ice and ſalts may, if required, be haſtened by adding occaſionally a little water; but then the cold produced will be leſs intenſe, and not ſo durable.

That particular form of the veſſel in which the ice is made and reduced to powder, is choſen becauſe it ſubjects the powdered ice in the tube to the conſtant action of the freezing mixture, without which it would be leſs fit, particularly in warm weather, for the intended uſe, and becauſe in it the ice is not liable to be impregnated with the ſalts of the mixture, by which it would be utterly ſpoiled: and *that* for cooling the nitrous acid, and making the ſecond mixture in, becauſe it is ſteady, and is beſides inſulated as it were from the external warm air, and ſurrounded in its ſtead by an atmoſphere much colder.

It is ſcarcely neceſſary to add, that when ſnow which has never thawed can be procured, it may be cooled in this apparatus by a mixture of ſnow

(inſtead

(inſtead of the pounded ice), and the ſalts, and the trouble of reducing the ice into powder, ſaved.

I prefer the *red fuming* nitrous acid,* becauſe, as I have obſerved in a former paper, it requires no dilution. Being however under the neceſſity at one time of uſing the *pale* nitrous acid,† I found it required to be diluted with one-fifth its weight of water.

The beſt and only way of trying or reducing any acid to the proper ſtrength, is by adding ſnow, as Mr. CAVENDISH directs, (Phil. Tranſ. vol. lxxvi, p. 143.) or the powdered ice to it, until the thermometer ceaſes to riſe; then cool the acid to the ſame temperature of the ſnow again, add more ſnow, which will make the thermometer riſe again, though leſs; cool it again, and repeat this, until the addition of ſnow or powdered ice will not make the thermometer riſe: to be very accurate, it ſhould be reduced in this manner to the proper ſtrength, at the temperature whatever it be, at which the nitrous acid and ſnow, or powdered ice, are to be mixed together when cooled.

In the courſe of my experiments I have endeavoured to aſcertain the comparative powers of ice to produce cold with nitrous acid, in the different

* *Phlogiſticated* nitrous acid. † *Dephlogiſticated* nitrous acid.

different forms I have had occafion to ufe it. The refult is, that frefh fnow funk a thermometer to —32°, ground ice to —34°, and the moft rare frozen vapour to below —35°; the veffel and materials each time being 30°.

The veffels for thefe mixtures, particularly that in which the quickfilver is to be frozen, fhould be thin,* and made of the beft conductors of heat; firft, becaufe thin veffels rob the mixture of lefs cold at mixing, *i.e.* if two mixtures of the fame kind are made, one in a thin, the other in a thick veffel, the former will be coldeft; fecondly, becaufe the air is a fufficiently bad conductor; and thirdly, for the very obvious reafon, that the cold is tranfmitted through them quicker.

For thefe reafons, and from the difficulty I have found in procuring veffels of glafs, which are undoubtedly fitteft for experiments of this kind, I have ufed tin; which is readily had in any form, and if coated with wax, is fufficiently fecured, againft the action of the acids.

I give the infide fuch a coating, by pouring melted white wax into the veffel, previoufly clean

* Some cold is loft, by the heat which the veffel communicates to the mixture in which it is made; this I have feldom found to be lefs than *two degrees*, even in the thinneft veffel.

clean and dry, and turning it about by hand, ſo as to leave no point of the metal uncovered for the acid to act on, pouring the ſurplus away.

The whole of this apparatus may be of tin, that part *only* (when the *cooling* mixtures are made *without* uſing any corroſive acid) in which the *acid mixture* is to be made, being previouſly coated in the manner above mentioned.

I have occaſionally uſed a thin glaſs tumbler for the mixture in which the quickſilver is to be frozen, immerſing it with the acid in a frigorific mixture till the acid is ſufficiently cooled, then adding the ground ice to it, previouſly removing the tumbler out of the frigorific mixture; this ſimplifies the apparatus, but is leſs convenient on many accounts.

The ſcale of this apparatus may be diminiſhed or increaſed at the will of the operator; for there is no doubt that a ſmall quantity of quickſilver may be frozen at any time with one-fourth of this quantity, with an apparatus of this kind, by any one converſant in ſuch experiments. I have frequently frozen quickſilver, by mixing together, at 6°, three drams of ground ice with two drams of nitrous acid.

Whenever the intention is, as in thefe experiments, to cool the materials to *nearly* the fame temperature with the frigorific mixture in which they are immerfed, the proportion of the frigorific mixture to the intended mixture, or materials to be cooled, fhould not be *lefs* than twelve to one; a greater difproportion is ftill better.

By attending to the directions *particularly* mentioned in the experiment made on Dec. 28, a thermometer may be *always* difpenfed with; the proportions of the materials to be cooled being exactly adjufted; and *when* they are to be mixed precifely determined, by the time employed in grinding the ice to powder.

The proportions of fnow, or pounded ice and falt, or falts, may be gueffed fufficiently near without weighing, unlefs in very *nice* experiments.

Imagining that a recapitulation of the different mixtures, defcribed in my former papers, for producing artificial cold, brought into one view might not be un-ufeful, I have fubjoined a table of the falts, their powers of producing cold with the different liquids, and the proportions of each, acording to a careful repetition of each; the temperature being 50°.

Salts

| Salts. | Liquor. | Temperature, or cold produced. |
|---|---|---|
| * Sal ammoniac 5, nitre 5 - - - - | water 16 | 10° |
| Sal ammoniac 5, nitre 5, GLAUBER's salt 8 | —— 16 | 4° |
| * Nitrous ammoniac 1 - - - - - | —— 1 | 4° |
| Nitrous ammoniac 1, sal soda 1 - - - - | —— 1 | — 7° |
| † GLAUBER's salt 3 - - - | d. nitr. acid 2 | — 3° |
| GLAUBER's salt 6, sal ammoniac 4, nitre 2 | —— 4 | — 10° |
| GLAUBER's salt 6, nitrous ammoniac 5, - - | —— 4 | — 14° |
| Phosphorated soda 9 - - - - - | —— 4 | — 12° |
| Phosphorated soda 9, nitrous ammoniac 6 - | —— 4 | — 21° |
| † GLAUBER's salt 8 - - - | marine acid 5 | 0° ‡ |
| † GLAUBER's salt 5 - - - | d. vitr. acid 4 | 3° ‡ |

I have chosen the temperature of 50°, because the materials may at any time by immersion in

 water

N. B. The figures after each salt, and after the liquor, signify the proportion of parts, by troy-weight, to be used; the trouble of weighing the *water* may be saved by observing, that a full ounce of it by wine-measure corresponds exactly with one ounce of it by troy-weight; likewise it must be noticed, when more kinds of salts than one are used, to add them to the the liquor one after the other, in the order they stand in the table; beginning on the left hand, and stirring the mixture well between each addition: d. nitr. acid, is red fuming nitrous acid two parts, and rain, or distilled water one part, by weight, well agitated together, and become cool: d. vitr. acid, is strong vitriolic acid, and rain, or distilled water, equal parts, by weight, thoroughly mixed (very cautiously) and cooled.

* The salts from each of these may be recovered by evaporating the mixture to dryness, and used again repeatedly.

† The materials from each of these may be recovered for use again, by distillation and chrystallization.

‡ The cold in each of these mixtures may be likewise increased by the addition of sal ammoniac, and nitre.

water drawn from a ſpring, be cooled nearly to that temperature, and the experiment for freezing with any of theſe mixtures commence there.

At a higher temperature than 50°, the quantity of the ſalts muſt be increaſed, and the effect will be proportionably greater; at a lower temperature diminiſhed, when the effect will be proportionably leſs.

It muſt be obſerved, that to produce the greateſt effect by any frigorific mixture, the ſalts ſhould be freſh cryſtallized,* not damp, and newly reduced to very fine powder; the veſſel in which they are made, very thin, and juſt large enough to contain the mixture; and the materials mixed intimately together, as quickly as poſſible, the proper proportions at any temperature (thoſe in the table being adjuſted for the temperature of 50° *only)* having been *previouſly* tried by adding the powdered ſalts gradually to the liquid, till the thermometer ceaſed to ſink; obſerving to produce the full effect of one ſalt before a ſecond is added, and likewiſe of the ſecond before a third is added.

* Soda, phoſphorated ſoda, and Glauber's ſalt, are beſt chryſtallized afreſh, becauſe their effect, eſpecially the two laſt in the acids, depends upon the quantity of water they contain in a ſolid ſtate.

Neither ſoda, phoſphorated ſoda, nor Glauber's ſalt ſhould be mixed with nitrous ammoniac, or the powder compoſed of ſal ammoniac and nitre, unleſs at a low temperature, *i. e.* below 0°, but pounded and kept apart.

In the experiments alluded to in the table, the precaution of freſh chryſtallizing the ſalts was not obſerved, becauſe I choſe to give the ordinary effects only; I therefore then uſed ſalts in their common ſtate, taking care, however, to chooſe ſuch as had not in the leaſt effloreſced.

Since it is always uſeful, and generally abſolutely neceſſary, to know how much room in a veſſel the ſeveral materials take up ſeparately, and when mixed, it will be right to obſerve, that ſnow, or ice in powder, at near 0°, occupy in meaſure nearly two thirds more than their weight; that is, one ounce weight of water will, when in the form of ſnow, or ice ground to powder, nearly fill a veſſel which holds three ounces wine-meaſure; powdered ſalts nearly double their weight; ſtrong nitrous acid, about three-fourths its weight; and a mixture made of ſalts and diluted nitrous acid, meaſures rather leſs than two-thirds of the weight of the ingredients. Without a previous knowledge of this, it is impoſſible to adjuſt the ſize of the veſſels to the

the mixtures which are to be made; becaufe, in moft nice experiments of this kind, the height to which a veffel will be filled is indifpenfably neceffary to be known beforehand.

The long continuance of the late froft having afforded me opportunities of repeating thefe experiments in various ways, I fhall mention briefly the refult of fuch as appear to me to be material.

I have found, that ice may be ground fo fine as to be equal to frozen vapour, and the harder it is frozen the finer it is ground, but with more labour:

That quickfilver may be frozen by cooling the nitrous acid only, faving the trouble and inconvenience of cooling the fnow likewife; either by adding fnow at 32°, to nitrous acid at —29°; or fnow at 25°, to nitrous acid at —20°; or fnow at 20° to nitrous acid at —12°; moft winters offer an opportunity of doing it in this way; the nitrous acid may be cooled in a mixture of fnow and nitrous acid:

That it may likewife be frozen, by mixing expeditioufly together fnow and nitrous acid, when the temperature of each is 7°:

Or, by mixing ground ice and nitrous acid at 10°.

Hence

Hence it follows, that the cold of this climate offers occaſionally opportunities of freezing quickſilver, without previouſly cooling by art the materials to be mixed; for I have once ſeen the thermometer at 6°, and others, I believe, have ſeen it lower.

I expected an opportunity would have offered this winter, but the loweſt point I ſaw my thermometer at, this ſeaſon, was only 10°; at this temperature, I mixed nitrous acid (cooled out of doors to the temperature of the air) and ſnow, on January 23d laſt; but the cold produced was not quite ſufficient to freeze the quickſilver, although very near it, as indicated by a thermometer: but from what I have obſerved *ſince* theſe latter experiments were made, I think it may be reaſonably expected, that powdered ice and nitrous acid at 14°, or ſnow at 10°, will ſucceed, if mixed expeditiouſly.

Strong ſpirit of vitriol, whoſe ſpecific gravity is 1,848, required to be diluted with half its weight of water, and produced with ſnow at the temperature of 30°, about eight degrees leſs than with nitrous acid, ſinking the thermometer to —24°; four parts of the diluted vitriolic acid required, at that temperature, ſix parts of ſnow.

It

It perhaps will be remarked, that I have taken no notice before of the vitriolic acid. The reason is, becaufe the freezing point of quickfilver being —39°, it may be frozen tolerably hard by a mixture of nitrous acid with fnow, or ground ice, though the utmoft degree of cold this acid can produce with fnow is —46; * which degree of cold may be produced by mixing the fnow or ground ice and nitrous acid at 0°.

If it be required to make it perfectly folid and hard, a mixture of equal parts of the diluted vitriolic acid and nitrous acid fhould be ufed with the powdered ice, but then the materials fhould not be lefs than —10° before mixing.

If a ftill greater cold be required than a mixture of that kind can give, which is about —56°,* the diluted vitriolic acid *alone* fhould be ufed with fnow or powdered ice, and the temperature at which the materials are to be mixed not lefs than —20°. †

Select

* The power of each of thefe mixtures for producing further cold, is limited at the temperatures mentioned; in confequence of having arrived at, or very near, to that degree of cold, at which the mixture itfelf would freeze, viz. at its point of *aqueous* congelation. *See the note at page* 16.

† The utmoft degree of cold, which a mixture of diluted vitriolic acid, and fnow *can* produce, is not yet known: the greateft

Select, according to the intention, either of the three following mixtures:

First; snow, or pounded ice, two parts, † and common salt one part, which produces a cold of —5°:

Second; snow or pounded ice twelve parts, common salt five parts, and a powder, consisting of equal parts of common sal ammoniac and nitre mixed, five parts, which produces a cold of —18°:

Third; snow or pounded ice twelve parts, common salt five parts, and nitrous ammoniac in powder five parts, which produces a cold of —25°.

The proportions which I have found to be the best for mixing the snow or powdered ice with the different acids, at different temperatures, are these; *viz.* at 30°, seven of the former to four of the nitrous acid; at 5° (with a trifling allowance,

greatest degree of artificial cold hitherto produced is —78½; this was effected with a mixture of this kind, by Mr. M'NAB, at Hudson's Bay. Phil. Trans. 1786, p. 266.

Thermometers filled with rectified spirit of wine, (that liquor never having yet been frozen), are now used to indicate any degree of cold exceeding —39; quicksilver thermometers being useless *below* that temperature.

† Unless the ice be reduced to fine powder, the proportion of that to the salt should be three (instead of two) to one.

ance, if any, for a few degrees above or below), three to two; at —12°, four to three, with the mixed acids; and at —20°, with the diluted vitriolic acid, equal parts.

If it be required to prepare the materials in a frigorific mixture, *without the uſe of ice*, a mixture of the proper ſtrength may be choſen from the Table.

It is immaterial, when the exact proportions of each are known, whether the powdered ice be added to the acid, or the acid poured upon that, provided the powdered ice be kept ſtirred to prevent lumps forming, and the materials be mixed as quick as poſſible. But when the proportion is not known, it is better to be provided with more powdered ice, than is expected to be wanted; and add it to the acid by degrees, until the greateſt effect is produced, as ſhewn by a thermometer.

The conſiſtence is a pretty ſure guide to thoſe accuſtomed to mixtures of this kind; *viz.* when freſh additions of ſnow or ice do not readily diſſolve in the acid, though well ſtirred, and the mixture acquires a thickiſh flocculent appearance.

Snow, or powdered ice, that have ever been ſubjected

ſubjected to a cold leſs than freezing are ſpoiled, or rendered much leſs fit for experiments of this kind.

I prefer the method of adding powdered ice or ſnow to the acid in a *ſeparate* veſſel, principally becauſe the ſize of that veſſel may be *exactly* adjuſted to the quantity of mixture it is to contain.

A mixture made of diluted nitrous acid, phoſphorated ſoda, and nitrous ammoniac (by much the moſt powerful of any compounded of *ſalts* with acids) prepared with the greateſt accuracy, is not quite equal to a mixture of ſnow and nitrous acid, each mixed at 30°, although very nearly ſo.

Though quickſilver may be frozen by ſalts diſſolved in acids, it is neceſſary that the materials be cooled, previouſly to mixing, much lower than when ſnow or ground ice are uſed.

If it be required to mix the powdered ſalts and acids at a low temperature, the beſt method is this: put firſt the nitrous ammoniac into the large tube of ſuch an apparatus as fig. 7. ſhaking it down level, gently preſſing the upper ſurface ſmooth; then the phoſphorated ſoda, or GLAUBER's ſalt; cover this with a circular piece of writing

writing paper, and pour a little melted white wax upon it, and when cold, pour upon this the diluted nitrous acid; immerſe this in a frigorific mixture till it is ſufficiently cold, as found by dipping the thermometer into the liquor occaſionally; force a communication through, and ſtir the whole thoroughly together, contriving that the upper ſtratum of ſalt, that is, the phoſphorated ſoda or GLAUBER'S ſalt, be mixed with the liquor firſt, and then the nitrous ammoniac; the powdered ſalts do not require ſtirring whilſt cooling, like ſnow, for however hard they are frozen, they will readily diſſolve in the acid; care muſt be taken that the partition be perfect between the ſalts and liquor; and that in this, and every inſtance where the materials are to be cooled, they be immerſed *below* the ſurface of the frigorific mixture.

The ſtrength of the red fuming nitrous acid, uſed in theſe experiments, I found to be 1,510, and that of the vitriolic acid 1,848.

Theſe experiments were chiefly made in a warm room, not far from the fire ſide.

I have now finiſhed my propoſed plan reſpecting the beſt modes of conducting experiments on cold; in which it will appear, that I have

have reduced the congelation of *quickſilver*, in any climate, at any ſeaſon, to as certain, and almoſt as eaſy a proceſs, as that I originally ſet out with, for the freezing of *water*, *viz.* by previouſly cooling the materials in one mixture, to produce the effect in a ſecond.

It may very likely appear to ſome, that I have been too minute in a few particulars; yet as perhaps experiments of this kind, all circumſtances conſidered, are inferior to few in the delicacy required to make them ſucceed completely, I truſt I ſhall be excuſed by thoſe who chooſe to repeat them, particularly ſuch as are not in the habit of making experiments of this kind; eſpecially if it ſecure them from an unſucceſsful attempt, and that, perhaps, without being able to account for it.

OXFORD,
*March* 1, 1795.

The

The following is a TABLE of the Proportions of the component Parts of the different SALTS used in these Experiments; taking *one Hundred Parts* of each of the Salts in a perfect State. And likewise, the Quantity of Water which each Salt is soluble in, at the Temperature of 50°.

| 100 parts of | contains of | | | | | | and requires, its weight of water to dissolve it. |
|---|---|---|---|---|---|---|---|
| MINERAL ALKALI; NATRON; or SODA, | Pure Soda | 20 parts, | Aerial Acid | 16 parts, | Water | 64 parts, | 2 |
| GLAUBER'S SALT, | ——— | 16 | Vitriolic Acid | 26 | —— | 58 | 3 |
| EPSOM SALT, | Magnesia | 20 | ——— | 35 | —— | 45 | 1 |
| SAL AMMONIAC, | Pure Volatile Alkali | 40 | Muriatic Acid | 52 | —— | 8 | 6 |
| NITROUS AMMONIAC, | ——— | 12 | Nitrous Acid | 80 | —— | 8 | 1 |
| NITRE, | Pure Kali | 32 | ——— | 63 | —— | 5 | 7 |

Phosphorated Soda; a neutral Salt, consisting of pure Soda and Phosphoric Acid, (being but lately known), is omitted in the above TABLE.

It is very well known, that vitriolic ether will produce ſufficient cold by evaporation to freeze water; this circumſtance is noticed by many, and ſeveral different methods have been propoſed, particularly one by Mr. CAVALLO, * with a very

* Mr. CAVALLO's method conſiſted in applying a ſmall ſtream of ether to the *naked* bulb of his thermometer, through a capillary tube, connected with a ſmall phial, containing the ether, by which means he brought the thermometer down, when the air was ſomewhat warmer than temperate to 3°, and in any ſeaſon of the year, converted a ſmall quantity of water, contained in a glaſs tube to ice. Mr. C. likewiſe gives a method of purifying ether, which is thus: To a given quantity of common ether, add double the quantity of water; theſe are to be agitated together, and after reſting three or four minutes, the water is be ſuffered to run out from the ether through the mouth of the inverted bottle; more water is then to be added to the ether, and the ſame operation repeated three or four times; the ether which is now left on the ſurface of the water, but much reduced in quantity, will be exceedingly pure.—Phil. Tranſ. 1781.

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Dr. FRANKLIN, aſſiſted by Dr. HADLEY, produced an extraordinary degree of cold, by evaporation, with ether, in which account they ſunk the thermometer, Dr. F. ſays, from 65°, the temperature of the air at that time, down to 7°; this experiment was conducted in the uſual way, that is, by repeatedly and alternately wetting the *naked* bulb with ether, and blowing upon it with a pair of bellows to quicken the evaporation.—FRANKLIN's Experiments and Obſervations on Electricity and other Philoſophical Subjects.

Whatever haſtens the evaporation of the ether, increaſes its

a very ingenious apparatus for the purpose (Phil. Transf. vol. lxxi); neverthelefs, as I am upon the fame fubject, and the following experiments differ, as well in the effect produced as in the particular mode of conducting them, from any I have met with, I have ventured to mention them.

June 29, 1792, temperature of the air 71°, I funk a thermometer (the bulb being covered with fine lint tied over it, and clipped clofe round), by dipping it in ether, and fanning it, to 26°; then by expofing the thermometer to the brifk thorough air of an open window, to 20°; and again, by ufing fome of the fame ether, but which had been purified by agitating it with eight times its weight of water, applied exactly as in the laft experiment, the thermometer funk to

its effect this way: thus, Mr. NAIRNE mentions an experiment made for producing artificial cold, by the evaporation of ether placed under the receiver of Mr. SMEATON's improved air-pump; in which, *it is faid*, the thermometer funk from 55°, (the temperature of the air in the room at the time) to 48° below 0°.—Phil. Tranf. 1777.

Vitriolic ether (the lighteft and moft evaporable liquor known) is faid to be fo extremely volatile, that its parts are kept together by the preffure of the atmofphere only; if that therefore were taken off, it would inftantly vanifh: hence, perhaps, it might be reafonable to expect the completeft effect, by fubjecting ether to a torricellian vacuum.

to 12°.* Water tried in the ſame manner, at the ſame temperature, ſunk the thermometer to 56°.

A whirling motion was given the thermometer during each experiment.

The lint was renewed for each experiment, and the bulb required to be dipped into the ether thrice; the firſt time ſufficiently to ſoak it, after which the thermometer was held at the window till it ceaſed to ſink; then a ſecond *quick* immerſion, and likewiſe a third, expoſing the thermometer in like manner after each immerſion.

In this manner a little water in a ſmall tube may be frozen preſently, by good ether *not purified*, at any time, eſpecially if a ſmall wire be uſed to ſcratch or ſcrape the ſides of the tube, below the ſurface of the water. *See p.* 28.

During the warmeſt weather of laſt ſummer, I frequently froze water in this way.

May 27, 1795. The temperature of the air being 50°; likewiſe very briſk, and dry; which I have found to be the moſt favourable ſtate of the air for producing cold by evaporation: I

 took

* I could never ſink a thermometer near ſo low, by applying ether to the *naked* bulb.

took an opportunity of afcertaining the degrees of cold which might be produced at that temperature by this procefs, with the ufe of vitriolic ether, rectified fpirit of wine, and water: the bulb of the thermometer in each inftance being covered with a fingle ply of fine lint, put on with the down *outwards*; and the experiment conducted exactly as in the method laft mentioned. The refult was, that the ether funk the thermometer to 5°, rectified fpirit of wine to 31°, and water to 38°. Having likewife in the courfe of the preceding winter frequently fucceeded in producing ice, by the cold produced from evaporation with water, when the temperature of the air was 38°; it occurred to me, that it might be poffible to freeze water in the middle of fummer, by a procefs which depended on this principle, by the ufe of water only.

Accordingly I procured a tall cylindrical veffel, holding about two gallons,* in which is fixed a fmall fpiral tube, as in the worm-tub of a common ftill; the lower end of this tube comes out through the veffel near the bottom, fufficient to connect the nofle of a pair of bellows to it, by the intervention of a bladder, fecured air-tight: this fpiral tube ends at the top of the cylindrical veffel, where it is fomewhat enlarged, like the mouth of a funnel; (fee the plate, fig. 11.) this veffel being covered with flannel, was filled

* This veffel is filled at a fmall aperture in the top.

filled with water and hung out in a brifk dry wind, the temperature of the air being 50°; after fome time, by repeatedly wetting the flannel on the outfide the veffel, I found the water within was cooled to 40°; air being then forced through the tube (by means of the bellows), furrounded by the cooled water, came out at the upper extremity of the tube at nearly the fame temperature.

A thermometer, having its bulb covered with lint and wetted repeatedly with the cold water in the veffel, placed fo as to receive the draught of cold air from the tube, foon funk to 34°;* hence by a feries of two or three of thefe veffels, water might, upon this principle, be frozen at midfummer, recollecting that this experiment may *always commence* at 50°, the ufual temperature of fprings: and hence it might be poffible upon the fame principle, to caufe nature upon a fmall fcale, even without the *immediate* interpofition of art, to depart from her ufual courfe, and to affume the hoary garb of winter at midfummer.

For this purpofe, a current from the external air might be admitted into the tube by means of a funnel, communicating with, and receiving, a conftant draught of air.

In an attempt of this kind, it would be neceffary (befides fome other variation in the

 veffels,

* The object of this experiment was merely curiofity; but it ferves to fhew to what extent evaporation may be carried.

veſſels, which circumſtances might point out) that the cylindrical veſſels be porous, or pierced with ſmall holes, ſo that the water may be conſtantly and gently oozing out.

Theſe diſcoveries I have the ſatisfaction of being aſſured are already conſidered as no trifling addition to the general ſtock of philoſophical knowledge; and I flatter myſelf they will be conſidered hereafter as a new and valuable acquiſition to the hitherto parched inhabitants of the torrid zone; for they not only furniſh thoſe with the means of enjoying the comfortable and ſalutary effects of cool liquors, and the luxury of ices, and at a price not greatly exceeding that at which they are procured in the hot ſeaſons of cooler climates; but *may* likewiſe be extended even to cooling the very air which they breathe: for I have no heſitation in declaring, that the air of a room in the hotteſt part of the world *may* be cooled, to any temperature deſired, and the ſame preſerved any length of time.

Upon this conſideration I ſhall add a word or two more concerning the beſt mode of its application:

Firſt, I ſhall obſerve, that a veſſel containing a convenient quantity of water may be immerſed over night, in ſo much of either of the freezing mixtures

mixtures as will, according to the temperature of the place and heat of the feafon, convert the water into ice by the next morning. The ice thus made, may be ufed throughout the day with common falt, in the ufual way;* and the materials recovered for ufe again by evaporation, or diftillation and cryftallization.

Secondly, Ice once generated, may, by the following method, be *accumulated* in confiderable quantities, at a fmall expence: in the plate, (fig. 10.) I have given a reprefentation of an apparatus which I fhall call an ice-accumulator; it confifts of a veffel, upon which fits a cover, into which cover is fixed any number of cylindrical tubes (in the plate only five are reprefented, in order to convey an unconfufed idea of it), placed at equal diftances;† it is ufed



thus:

* The method ufed in the Eaft Indies for freezing creams, &c. as fubjoined by Sir ROBERT BARKER to his account of the procefs ufed there for procuring ice, *fee note at page* 21, is the following:—The fherbets, creams, or other liquids intended to be frozen, are confined in thin filver cups, of a conical form, containing about a pint, with their covers well luted on with pafte, and placed in a large veffel filled with ice, nitre, and common falt, of the two laft an equal quantity, and a little water to diffolve the ice and combine the whole.

† In the fmall apparatus of this kind which I have, there are fixteen tubes, each of which will contain half an ounce of water; and the veffel for the freezing mixture contains, when the

thus: a ſufficient quantity of freezing mixture, is put into the veſſel; then the cover, with its tubes filled with water, is put on; as ſoon as the water in the tubes is frozen ſolid, the cover is to be taken off, and the tubes immerſed in water at a warmer temperature, till the cylinders of ice are looſe enough to be thrown out into a ſieve, or any reſervoir full of holes; the tubes are then to be again filled with water, and ſubjected to the freezing mixture; this is to be repeated as long as the frigorific mixture will produce its proper effect; it is better to have two covers, each having a ſimilar ſet of tubes; for then, no time is loſt, one ſet or the other being conſtantly in the frigorific mixture. When by this means a ſufficient quantity of ice is generated, a freezing mixture of *ice and ſalt* may be ſubſtituted for the chemical mixture at firſt uſed, and the proceſs conducted in the ſame manner; thus, one pound of ice (originally generated by a *chemical mixture)* with a proper proportion of ſalt, will, in a hot climate, if managed œconomically, produce at leaſt three pounds of ice;* therefore

the lid (with the tubes fixed in it) is on, two quarts. The principle of this method is too evident to require a comment; and any variation, or additional number of veſſels, may be ſuggeſted, as different circumſtances occur.

* It muſt be underſtood here, that I do not pretend to have aſcertained the *exact proportion* of ice which might thus be

therefore a very considerable quantity of ice, may, in a short time, and at very little expence, be accumulated from a very small portion; and if more than one apparatus be employed, that is, if a second freezing mixture is prepared as soon as the first has acquired too much heat to produce the effect of freezing; and after that a third, and so on; the water may then be cooled progressively, by immersing it first in the *warmest*, and on by degrees to the *coldest*; each in succession, and by that means the portion of ice accumulated will be wonderfully increased.

Although I consider the methods above mentioned as applicable to hot countries only, yet, as the winters of colder climates are sometimes too mild to furnish any natural ice, the above method may be perhaps occasionally had recourse to here.

In latitudes under 35°, I am informed, frost is scarcely ever experienced. Therefore it is probable, that hereafter these observations may become very extensively useful.

be produced in a hot climate, or even in the hottest weather here; having had neither sufficient leisure nor inclination for such an experiment; but I have ascertained the general fact, that ice *may*, by this means, be speedily and *considerably accumulated* in the hottest weather of this climate.

RECA-

# RECAPITULATION.

By an examination of the Introduction, it will be found, that the means of producing Artificial Cold, without the uſe of ice, has long been an object of inveſtigation, and that various attempts have been made, with this view, by Mr. Boyle, Monſieur Homberg,* and others, to the very time when theſe experiments were undertaken.

It likewiſe appears that no chemical mixture had been diſcovered capable of producing cold ſufficient for generating ice in the ſummer of ſuch a climate as England.

Therefore we may conclude, the firſt time, that ice was *thus generated* by a chemical mixture, was on July 18, 1786.—*See page* 3.

Having reflected on my ſucceſs with a ſolution of ſalts in *water*, and likewiſe, on the great degree of cold which is produced by ice (ſnow) and the mineral acids, and the ſimilar proper-

ties

* The experiment of M. Homberg, *ſee Introd. page* ix, was originally publiſhed in the Memoirs of the French Academy of Sciences for 1700, p. 116.

ties of GLAUBER's ſalt to ice, I reſolved to try the effect of this ſalt in the mineral acids, *p.* 5; and, from the event, was led to believe I had diſcovered the means of freezing water, or other liquids, in *any* climate.

The Experiments on the Congelation of Quickſilver, recited in the third paper, were chiefly inſtituted for the purpoſe of confirming my experiment, *ſee page* 7, made for freezing that metal with mixtures of ſalts and mineral acids, merely with a view of exhibiting the unlimited power of theſe mixtures.

With reſpect to my experiment, on the cooling of water ſo far below its freezing point, in which I have aſcertained a curious fact, viz. that *common water*, under certain circumſtances, will reſiſt, without freezing, the utmoſt cold almoſt, to which this climate is ſubject, *p.* 25; and likewiſe the particular kind of agitation,* which moſt

* Dr. BLAGDEN in his curious paper " On the cooling of water below its freezing point :" remarks on the miſtaken opinion that *agitation of any kind*, facilitates the freezing of water, and mentions ſeveral trials he made to diſcover *that* particular agitation, which moſt frequently ſucceeded. *Phil. Tranſ.* 1788, *p.* 132, 133.—It is proper and curious to remark here, that my paper, in which the circumſtance alluded to is noticed, was tranſmitted to the Royal Society, *before* the above-mentioned paper of Dr. BLAGDEN's was publiſhed.

moſt facilitates the freezing of water, *p.* 27, 28. Theſe I conſider as incidental. I may add here, that I have ſcarcely ever failed to bring on the freezing of water, in the manner deſcribed; and this, however *thick* the veſſel might be, which contained the water, and whether I uſed a metallic, or a glaſs point; and a curious experiment enough it is.

Nitrous ammoniac, *p.* 15, produces, by ſolution in water, 49 degrees of cold.* I have frequently produced ice, by a ſolution of this ſalt in water, when the thermometer ſtood at 70°.

The method deſcribed in the fourth paper, *p.* 56, of imitating, or rather producing a ſubſtitute, for ſnow, by freezing water in a tube, and grinding the ice into fine powder, may be conſidered as a convenient and effective ſubſtitute for ſnow, which may moreover be produced at any time, and is, beſide, ſuperior to it in effect, *p.* 63, 64.

With reſpect to the probable utility of theſe diſcoveries, in hot climates, I think it may be reaſonably inferred, from the avidity with which, it is well known, ices and cool liquors

* Common ſal ammoniac, conducted in the beſt way, *ſee page* 2, produces only 32 degrees of cold by ſolution in water.

liquors are coveted in the ſummer of temperate climates; ſecondly, from the conſideration, as plainly appears, that no poſſible method was known *prior* to the original publication of theſe experiments in the *Phil. Tranſ. for* 1787; excepting by the uſe of ether, if that could effect it, and by the proceſs of evaporation, in climates where, in the winter ſeaſon, the natural cold approximates ſufficiently near for the purpoſe, as in ſome parts of the Eaſt Indies; *ſee the note at page* 21: and, thirdly, ſince it is certain that ſeveral of theſe frigorific mixtures will produce, *inſtantaneouſly*, a degree of cold ſufficient to freeze water, or creams, in any part of the world, at any ſeaſon:*—*Notes from page* 19 *to* 22.

At *pages* 23, 24, will be found a cheap and convenient proceſs for freezing water in the ſummer of this climate, or producing cold for other purpoſes, when ice is not at hand.

It may be obſerved, that a hoar froſt is always depoſited on the outſide of the veſſel (if not very thick) to the height of the mixture within; the continuance, or preſence of this, is a teſt, without the uſe of a thermometer, of the power of the mixture for freezing water.

I ſhall

* I have no doubt, bold as the aſſertion may appear, that I could cool the air of a room, even in Bengal, to below freezing.

I ſhall conclude this retroſpect by obſerving, that I have ſhewn, *page* 82, that it is *poſſible* to freeze water in ſummer by the aſſiſtance of air and water *only*.

I have choſen to recapitulate the above particulars, conſidering thoſe as the moſt eſſential, and wiſhing therefore to impreſs them more ſtrongly on the mind of the reader.

For the different freezing mixtures the beſt proportion of the materials, and their different powers,* *ſee the table at page* 67, and the directions which follow it.

Since it has been found that the effect of thoſe ſalts which produce cold, by ſolution in the mineral acids, is in proportion to the quantity of water contained in the cryſtals, the phenomenon ſeeming to depend entirely on that circumſtance; *ſee page* 47; and conſidering that their effect this way approximates ſo nearly to that

* The reaſon why there is ſuch a difference in the reſult of the ſame experiment made at different times, is becauſe the firſt object was diſcovery, afterwards preciſion; and as the greatneſs of the effect depends principally on the fineneſs of the powder, to which the ice or ſalts are previouſly reduced, ſcarcely any *preciſe* limits can be given.

that of ice,* which differs from the ſalts only in being *purely cryſtalized water;* one might be almoſt led to predict, that the frigorific mixtures deſcribed in the preceding papers will never be much exceeded. This conſideration, with the perſuaſion that theſe mixtures are adequate to any uſeful purpoſe, that can be required, has operated ſo far with me, as to preclude any attempts of mine to proſecute theſe experiments further.

It is probable that ſome may think lightly of theſe experiments, as conſiſting of little more than diſſolving various ſalts in different liquors. Of ſuch, if any there be, I ſhall, firſt reminding them that not one ſtep has been the reſult of accident, beg leave to be informed by what ſtrange infatuation it happened, that thoſe who preceded me in the inveſtigation of the ſame ſubject ſtopped at the very entrance, when ſuch an ample field for valuable diſcovery, as it now appears, lay open to them: and to remind them, ſo obvious ſeems a diſcovery, *when communicated*, that ſcarcely any thing new is found out, but our

* A mixture of ſnow and nitrous acid produces only three degrees more cold, than a mixture compoſed of phoſphorated ſoda, nitrous ammoniac, and diluted nitrous acid, each mixed at 32°.

our greateſt ſurpriſe is, that it ſhould have remained ſo long a ſecret.*

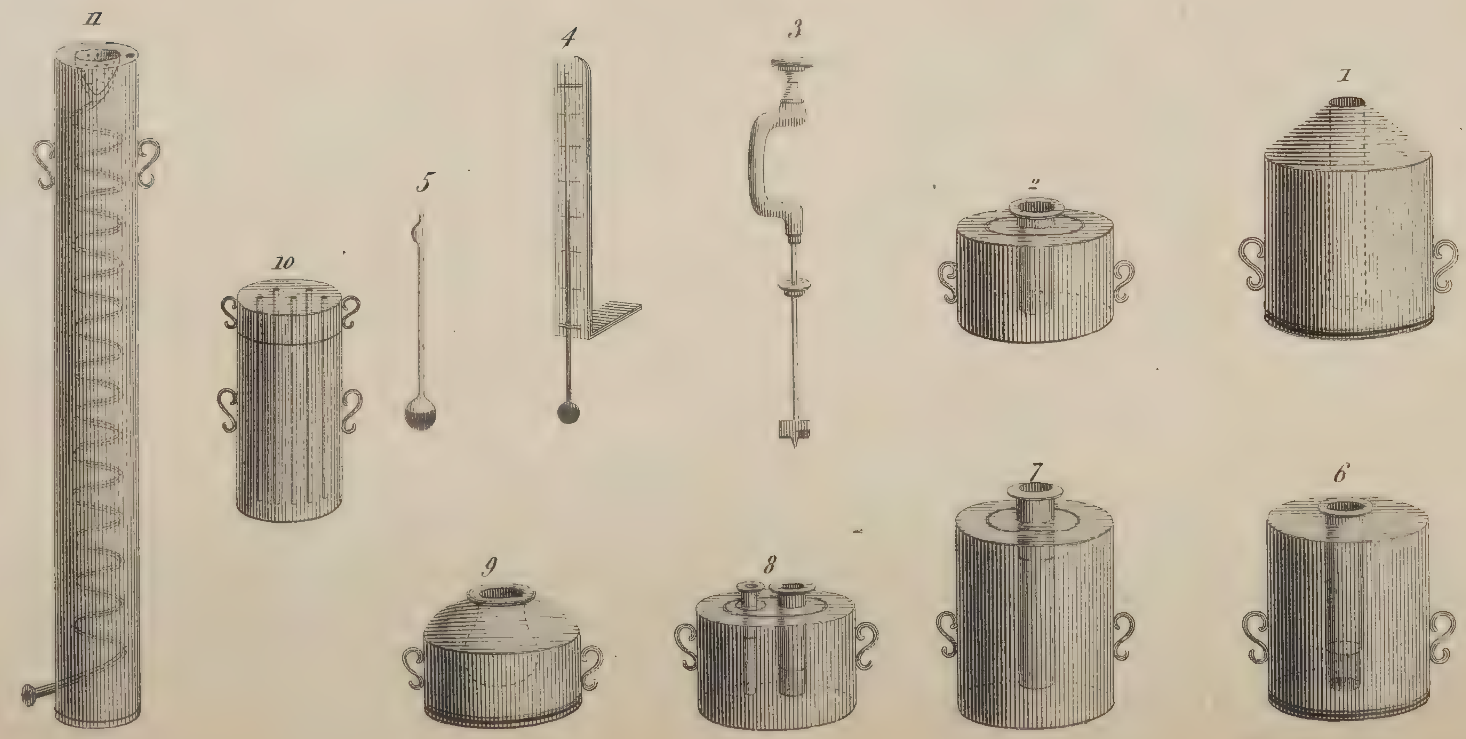
I ſhall now diſmiſs this ſubject with ſome degree of confidence, and a ſincere hope, that the employment of my leiſure hours may have afforded ſomething inſtructive, as well as curious; and that although I relinquiſh the ſubject, from a conſciouſneſs of being unable to extend it further myſelf,† I do not preſume to ſet limits to the courſe of nature, or wiſh to diſcourage the efforts of others, who may chooſe to take up the ſubject after me; but rather to enable ſuch to ſtart to the beſt advantage, by putting them in poſſeſſion of all the information in my power.

* Scarcely any perſon need be informed, that ſulphur, ſaltpetre, and charcoal, were familiarly known, long before any one thought of mixing them together to make gun-powder.

† It may be neceſſary to obſerve here, that there are a few other ſalts, which might be enumerated as inſtances of producing cold by ſolution in water or acids: but as the effect of ſuch are inconſiderable, compared to thoſe given, I have omitted them.

THE END.

Walker's Experiments on Artificial Cold.



# EXPLANATION OF THE PLATE.

Fig. 1. Reprefents a veffel in *one* piece; this veffel is open at the bottom, and has a tube, (reprefented by the dotted line) open at the top; the body of the veffel holds when inverted two pints; the tube will contain four ounces and a half.

Fig. 2. A veffel confifting of *two* parts, viz. the body, which holds a pint; and the tube (in one piece with the lid), which contains three ounces. The upper part of the tube rifes above the level of the lid juft fufficient to ferve for a handle. This veffel may be ufed inftead of the veffel fig. 9. *See page* 60.

Fig. 3. The inftrument for grinding the ice into powder, it works upon a fhort centre point, and has the edge bevelled contrary ways on each fide the point, fo as to follow. The finenefs of the powder is regulated by the degree of preffure ufed. The handle is wood, the reft metal: it has a cover which flips up or down; this cover, when it is ufed, fits on the tube in which the ice is ground, to exclude the external air, and to keep the inftrument fteady; the bottom of the handle forms a fhoulder or guard, to prevent the point of the inftrument from touching, fo as to endanger injuring, the bottom of the tube. The inftrument fhould be made, fo as to fit, without grating the infide of the tube in ufing. In the ufe of this inftrument, it muft be obferved, that in confequence of the projection of the point, (unlefs the bottom of the tube is made to receive it), a fmall quantity of the ice will remain unground, at the bottom of the tube; this quantity ought to be previoufly known, and allowed for.

Fig. 4. A thermometer, with the lower part of the fcale-board turned up with a hinge, for the convenience of taking the temperature of fmall quantities, or of mixtures, in which mineral acids form a part.

Fig. 5. A thermometer glafs, with the bulb three-fourths full of quickfilver.

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The above comprifes the whole of the apparatus neceffary, and moft convenient, for the purpofe of freezing Quickfilver.

Fig. 6, 7, 8, which follow, reprefent different forms of *fingle* veffels, which have occurred to me, for the fame purpofe: of thefe *Fig*. 8, with the inftrument *Fig*. 3, adapted to it, is, I think to be preferred; and would make a complete *portable apparatus*, particularly for experiments upon a fmall fcale.

Fig.

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Fig. 6. A veſſel in one piece. This veſſel is open at the bottom, and has a tube (repreſented by the lines) open at the top; the lower or ſmaller part of which is formed by a contraction or leſſening of the tube, in diameter, merely for the purpoſe of leaving a ſmall ſhoulder, for a temporary partition: the body of the veſſel holds, when inverted, two pints; the tube will contain five ounces, its lower or ſmaller part, containing rather *leſs* than one-fifth of the whole.

Fig. 7. A veſſel, conſiſting of *three* parts, viz. the body part, which holds two pints; and the lid with a tube, the upper part of which riſes above the level of the lid *juſt* ſufficient to ſerve as a handle, and within this a *ſmaller tube*, having a valve at the bottom.

Fig. 8. A veſſel, conſiſting of three parts, viz. the body, and the lid, with two tubes; the larger of which is in one piece with the lid, and the ſmaller tube takes in and out of the lid occaſionally, having a valve at the bottom. Each tube is marked with a diamond, at the height to which it is to be filled, the ſmaller one with the *acid*, and the larger with the *water* to be frozen.

Fig. 9. A veſſel of tin, open at bottom, with a cupping-glaſs, (as repreſented by the dotted line), cemented into it.

Fig. 10. A veſſel, in two parts, viz. the body, and the lid, with tubes, open at the top, cemented into and forming one piece with the lid.

Fig. 11. A cylindrical veſſel, deſcribed at page 82. The funnel part of the tube (at the top of the veſſel) is pierced with a number of ſmall holes, communicating with the tube, but not opening into the veſſel.

N. B. The tubes of each of the veſſels, fig. 1, 2, 6, 7, 8, ſhould be ſomewhat ſhorter than the veſſels, ſo as not quite to reach the bottom of it; and the veſſels 2, 6, 7, 8, muſt be entirely of glaſs: the veſſel 1, may be entirely of tin.

The veſſels 1, 6, 9, which are left open at the bottom, ſhould have a groove (as repreſented) to receive the ſtring in tying them over.

☞ The different veſſels *may* be made (of any ſize) according to the proportions given in the plate, without attending to the preciſe quantities it is ſpecified they ſhould contain.

Tubes of glaſs (not very thin) will reſiſt the expanſion of ice, without breaking, as I have commonly found, although immerſed in a cold of —15°, or greater.—Obſerve, to avoid the uſe of any *metallic* body with either of the mineral acids.

## ERRATA.

| | | | | | | |
|---|---|---|---|---|---|---|
| PAGE vii, | LINE | 21 | *for* | and | *read* | where he. |
| x, | —— | 7 | — | June 30 | —— | July 30. |
| 15, | —— | 8 | — | —8° | —— | 8°. |
| 22, | —— | 21 | *before* | as | *omit* | that. |
| 24, | —— | 6 | *for* | averdupois | *read* | avoirdupois. |
| 32, | —— | 9 | — | 46° | —— | —46°. |
| 39, | —— | 21 | — | narrow | —— | narrower. |
| 42, | —— | 17 | — | has | —— | as. |
| 49, | —— | laſt | *read* | by ſimilar figures of reference. | | |
| 71, | —— | 23 | *after* | leſs | *add* | cold. |